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KERR-McGEE CHEMICAL LLC
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1/10/02

January 16, 2002
FLKE-009

PHONE

630-293-6330

VIA FIRST CLASS MAIL

Mr. Fred Micke
U.S. EPA, Region 5
On-Scene Coordinator
Emergency Response Section #3
77 W. Jackson Blvd. (SE-5J)
Chicago, Illinois 60604-3590

SUBJECT: Results of Mineralogical and Radiological Analyses of Soil/Coal Ash samples and Literature Search Results on Natural Occurring Levels of Thorium in Coal and Coal Ash.

REFERENCE: DuSable Park, Chicago, IL

Dear Mr. Micke:

Kerr-McGee is submitting mineralogical and radiological analysis results for the two soil/coal ash samples that were collected from DuSable Park. Hazen Research, Inc. of Golden, Colorado performed the mineralogical analyses and Kerr-McGee performed the radiological analyses. We are also submitting the results of a literature search regarding naturally occurring levels of thorium found in coal and coal ash. As would be expected for naturally occurring radioactive materials at concentrations near background, neither the Hazen Report nor the radiological analyses provide definitive proof regarding the origin of the monazite in the samples. The information at hand demonstrates that the samples contain a substantial fraction of coal ash and that the concentration of thorium in the samples falls within the range reported in the literature for coal ash.

The Hazen Report, included as Attachment A, provides a summary of the mineralogical findings. The Area C sample was predominately coal, glassy slag particles, iron oxides and natural siliceous gangue particles. The Area B-2 sample showed less coal and more natural minerals. Three major forms of thorium were identified in the two samples. The forms were liberated monazite in rounded or angular particles, ThO₂ in glassy slag particles, and ThO₂ as fine liberated particles. Glassy slag particles would be expected in coal ash in the form of cinders. A summary of radiological analyses of the Hazen floatation samples and the bulk samples collected following the excavation are presented in the Attachment B spreadsheet.

An internet literature search was conducted to obtain information regarding the range of naturally occurring levels of thorium found in coal ash. This information has been assembled for your information and reference in Attachment C.

The West Virginia Geological and Economic Survey (WVGES) provided the following information on thorium and monazite in West Virginia coals.

"Monazite is a rare igneous mineral present in granite which weathers free, and because of its great resistance to chemical attack, is concentrated as a detrital mineral in sands. Monazite in coal occurs as a micron-size, and smaller detrital grains introduced into the coal swamp as a windblown or waterborne detrital material, ... and because of its great resistance is unaffected by acids in the swamp."

The US EPA Radiation Protection Program web site provided the following information regarding the range of naturally occurring radionuclides in coal ash.

"Coal contains trace quantities of the naturally occurring radionuclides uranium, thorium and potassium as well as their radioactive decay products. When coal is burned, minerals including most of the radionuclides do not burn and as a result are concentrated in the ash.

Wastes	Radiation Level [pCi/g]		
	Low	Average	High
Bottom Ash	1.6	3.5-4.6	7.7
Fly Ash	2	5.8	9.7

The US EPA collected five soil samples from the DuSable Park Site on October 7, 2002. The following table summarizes the values obtained for total radium. This radiological information has been previously submitted to the U.S. EPA.

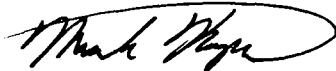
Area	Total Radium (Ra 226 + Ra228) (pCi/g)
A	5.3
B-1	1.1
B-2	4.7
B-3	3.5
C	8.0

The sample results of Areas A, B-1, B-2 & B-3 are all under the US EPA's release criteria of 7.2 pCi/g total radium. Sample C, which was predominantly coal, slag, iron oxides and siliceous gangue particles, was within the US EPA's published limits for naturally occurring radionuclide concentration in coal ash. Per the requirements of 40 CFR 302.6(c)(3), releases of radionuclides from the dumping and transportation of coal and coal ash, including the dumping and land spreading operations that occur during coal ash uses are exempt from the notification requirements of CERCLA. Section 40 CFR 302.6(c)(3) has been included as Attachment D.

Finally, we are including as Attachment E, the EPA NAREL report for the samples collected in October 2002. The NAREL data confirms the analyses performed earlier by Kerr-McGee. Please call me at (630) 293-6331 if you have any questions.

Very truly yours,

KERR-McGEE CHEMICAL LLC

A handwritten signature in black ink, appearing to read "Mark Krippel", enclosed within a large, loopy oval shape.

Mark Krippel
Program Manager

Attachments

cc: Mary L. Fulghum, Esq. (USEPA)
LeeAnn Tomas (Chicago Park District)

File: DPCH – EPA

FLKE-009

ATTACHMENT A

DETERMINATION OF SOURCE RADIOACTIVITY IN SOIL SAMPLES

Hazen Research, Inc.

December 12, 2002



Hazen Research, Inc.
4601 Indiana Street
Golden, Colorado 80403
Tel: (303) 279-4501
Fax: (303) 278-1528

December 12, 2002

Mr. Tom Gibson
Kerr McGee
800 Weyrauch Street
West Chicago, IL 60185

Subject: Determination of Source of Radioactivity in Soil Samples
Hazen Project 9939, Final Report

Dear Tom:

This letter report presents the results of electron microprobe analyses of two soil samples from Chicago to identify and determine the modes of occurrence of radioactive components (thorium series) responsible for elevated levels of radioactivity in these samples.

The two samples were received on October 11, 2002, and were designated Soil Sample Area C 10/4/01 and S001 Dusable Park Area B2 10/3/02. They weighed 784 and 570 g, respectively. The pertinent results, which were submitted previously by electronic mail, may be summarized as follows:

1. Three major forms of thorium were identified in the two samples; uranium-bearing components could not be detected.
2. In the Area C sample, thorium occurs predominantly as discrete, liberated, rounded and angular particles of monazite ranging from about 1 μm to over 300 μm . The majority of particles, in terms of weight contribution, range from 100 to 200 μm . Microprobe spot analyses of 28 particles showed thorium levels ranging from 6.3% to 19.1% ThO_2 with an arithmetic average of about 11% ThO_2 .

The identification of monazite is based on its composition of predominantly the rare earth (RE) elements lanthanum, cerium, and neodymium, in addition to phosphorus as determined by energy dispersive spectrometry (EDS).

Another form of thorium in the Area C sample occurs in low levels in glassy slag particles, varying from nondetectable ($<0.03\%$ Th) to 0.22% ThO_2 . Compositionally, the slag is high in aluminum, calcium, and iron, in addition to major silica. It appears that the thorium is molecularly dispersed through the glassy matrix and evidently does not occur in discrete phases.

Analyses of coal particles, which are abundant in the Area C sample, did not show any detectable thorium or uranium at a detection limit of approximately 0.05% (500ppm) for both elements. This detection limit applies to the organic part of the coal.

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3. In the Dusable Park Area B2 sample, thorium occurs principally as fine (1 to 20 μm), liberated particles of thorium oxide (ThO_2) and, to a much lesser extent, as monazite.

PROCEDURES

For sample preparation, the as-received sample was first split in half. One half was retained as is and the other half was wet screened at 200 mesh. The plus and minus 200-mesh fractions were dried, weighed, and checked with a survey meter, which did not show any elevated activity (above background) for either size fraction. Weight distributions of the fractions are presented in Table 1.

Table 1. Weight Distribution of As-received Samples

Sample	Weight, %	
	Plus 200	Minus 200
Area C	86.3	13.7
Dusable Park Area B2	83.4	16.6

The plus 200-mesh fractions were each crushed to minus 10 mesh, split with a riffle splitter, and briquetted for polished section preparation. Polished sections of each minus 200-mesh fraction were also prepared. All sections were examined microscopically and then subjected to electron microprobe analysis.

Following the initial results of the investigation (submitted by e-mail reports referred to above), it was agreed during telephone discussions with Kerr McGee representatives to subject the remaining uncrushed samples to physical separations in order to analyze the chief components by gamma spectrometry. The Area C sample was first sized at 14 and 200 mesh and then separated with heavy liquids at specific gravities of 1.65 and 2.96 to yield fractions rich in coal, glassy slag components, and heavies (including any monazite). The Dusable Park Area B2 sample was only wet screened at 200 mesh, since the thorium oxide identified previously was of a fine size. The weight distributions of the products are shown in Table 2 and all the fractions were sent to Kerr McGee, West Chicago, for the radiometric analyses.

Table 2. Weight Distributions of Screen and Heavy Liquid Separation Fractions

Sample	Weight	
	g	Distribution, %
Dusable Park Area B2		
Plus 200 Mesh	197.7	82.8
Minus 200 Mesh	41.1	17.2
Total	238.8	100.0
Area C		
Plus 200 Mesh	260.11	86.7
Plus 14 Mesh		
1.65 Float	67.92	22.6
1.65 by 2.96	109.7	36.6
2.96 Sink	7.73	2.6
Subtotal	185.35	61.8
14 by 200 Mesh		
1.65 Float	18.88	6.3
1.65 by 2.96	52.68	17.6
2.96 Sink	3.20	1.1
Subtotal	74.76	24.9
Minus 200 Mesh	40.0	13.3
Total	300.11	100.0

RESULTS

AREA C 10/4/02 SAMPLE

Initial microscopic examination of the two polished sections of the Area C sample showed predominantly coal, glassy slag particles, iron oxides, and natural siliceous gangue particles. The slag particles consist of two types: one consists of only a glassy phase, and the other carries exsolved iron oxides occurring as euhedral crystals or dendritic intergrowths. In the ensuing electron microprobe analysis, an initial search was made for particles that appear bright on the monitor screen due to abundant backscatter electrons produced from elements with high atomic numbers. Once located, any bright particles were then identified on the basis of their chemistry as determined by EDS for major elements and by wavelength dispersive spectrometry (WDS) for elements occurring in low concentrations. With this methodology monazite was readily located and identified based on its composition of predominantly the RE elements lanthanum, cerium, and neodymium, plus the exact amount of phosphorus and variable amounts of thorium. The monazite occurs as liberated, rounded and

angular particles. In the 10- by 200-mesh fraction, 11 particles ranging from <100 to over 300 μm and averaging 100 to 200 μm were analyzed. In the minus 200-mesh fraction, 17 particles ranging from about 1 to generally about 20 μm were analyzed.

The thorium concentrations for all 28 particles vary from about 6 to 19 % ThO_2 and average about 11 % ThO_2 . Table 3 summarizes the results of the analyses, and Figures 1 and 2 in the appendix show backscatter electron images for two monazite particles.

Table 3. Results of Electron Microprobe Spot Analyses of Area C Sample

Sample	Particle	Particle Composition	ThO_2	Size, μm	Comments
10 by 200 Mesh	1	$\text{REPO}_4 + \text{Th}$ (Monazite)	10.9	110	Liberated
	2	$\text{REPO}_4 + \text{Th}$ (Monazite)	15.5	120	Liberated
	3	$\text{REPO}_4 + \text{Th}$ (Monazite)	7.6	150	Liberated
	4	$\text{REPO}_4 + \text{Th}$ (Monazite)	12.7	90×160	Liberated
	5	$\text{REPO}_4 + \text{Th}$ (Monazite)	10.2	20×80	Liberated
	6	$\text{REPO}_4 + \text{Th}$ (Monazite)	9.9	90×180	Liberated
	7	$\text{REPO}_4 + \text{Th}$ (Monazite)	17.4	140×190	Liberated
	8	$\text{REPO}_4 + \text{Th}$ (Monazite)	9.7	120×210	Liberated
	9	$\text{REPO}_4 + \text{Th}$ (Monazite)	8.7	120×160	Liberated
	10	$\text{REPO}_4 + \text{Th}$ (Monazite)	8.2	140×210	Liberated
	11	$\text{REPO}_4 + \text{Th}$ (Monazite)	15.0	190×310	Liberated
Average			11.4		
Minus 200 Mesh	1	$\text{REPO}_4 + \text{Th}$ (Monazite)	6.7	12	Liberated
	2	$\text{REPO}_4 + \text{Th}$ (Monazite)	15.4	5	Liberated
	3	$\text{REPO}_4 + \text{Th}$ (Monazite)	6.3	2×4	Liberated
	4	$\text{REPO}_4 + \text{Th}$ (Monazite)	6.8	2.5	Liberated
	5	$\text{REPO}_4 + \text{Th}$ (Monazite)	12.7	9	Liberated
	6	$\text{REPO}_4 + \text{Th}$ (Monazite)	16.1	3.4	Liberated
	7	$\text{REPO}_4 + \text{Th}$ (Monazite)	18.0	1.2	Liberated
	8	$\text{REPO}_4 + \text{Th}$ (Monazite)	10.4	6	Liberated
	9	$\text{REPO}_4 + \text{Th}$ (Monazite)	6.4	6	Liberated
	10	$\text{REPO}_4 + \text{Th}$ (Monazite)	7.5	3.5	Liberated
	11	$\text{REPO}_4 + \text{Th}$ (Monazite)	19.1	3×5	Liberated
	12	$\text{REPO}_4 + \text{Th}$ (Monazite)	9.2	10×20	Liberated
	13	$\text{REPO}_4 + \text{Th}$ (Monazite)	9.4	7	Liberated
	14	$\text{REPO}_4 + \text{Th}$ (Monazite)	11.4	4	Liberated
	15	$\text{REPO}_4 + \text{Th}$ (Monazite)	14.2	13	Liberated
	16	$\text{REPO}_4 + \text{Th}$ (Monazite)	10.9	20-28	Liberated
	17	$\text{REPO}_4 + \text{Th}$ (Monazite)	12.3	20×80	Liberated
Average			11.3		

Other particles carrying high atomic number elements were found to be lead compounds. Following the initial identification of monazite, an effort was made to identify other occurrences that were most likely low-level thorium. This search yielded an unusual slag-like particle that consists of iron, calcium, aluminum, and major silica and has fine-grained spotty occurrences of RE phosphate carrying 1 to 2 % ThO₂. In addition, several glassy slag particles ranging from nondetectable (<0.03% ThO₂) to 0.22% ThO₂ were located.

These glass particles are high in aluminum, calcium, and iron, in addition to major silica, and lack any exsolved iron oxides. Slag particles carrying abundant discrete iron oxide phases did not show any detectable thorium. Figure 3 in the appendix shows the unusual slag particle, and Figures 4 through 7 present backscatter electron images, together with EDS matrix and WDS thorium analyses, for the glassy slag particles. For the particle shown in Figure 4, the EDS spectrum of the slag (top) and the WDS scan of the thorium peak (bottom) are shown in Figure 4a. The composition of only the first spot in each of the slag particles in Figures 4 through 7 is given.

Figure 8 illustrates an example of a slag particle with exsolved iron oxide crystals. Thorium could not be detected in particles with these characteristics. Microprobe analyses of the organic part of coal particles showed no detectable thorium or uranium at a detection limit of 0.05%(500 ppm) for both elements.

DUSABLE PARK AREA B2 10/3/2002 SAMPLE

The microscopic polished section examination of the Dusable Park Area B2 sample showed much less coal, fewer slag-type particles, and significantly more natural mineral particles compared with the Area C sample.

As in the previous sample, the 10- by 200-mesh and minus 200-mesh fractions were analyzed separately with the microprobe, which revealed that thorium occurs predominantly as thorium oxide. A small amount occurs as monazite. In the coarse fraction, three particles of thorium oxide and two particles of thorium-bearing monazite were located and in the fine fraction, 15 particles of thorium oxide and only a trace of monazite were found. In the latter fraction, the thorium oxide particles are liberated, vary in size from 1 to 20 µm, and occur mostly as irregularly shaped aggregates composed of elongated, more or less rod shaped crystals. Table 4 summarizes the results of the microprobe analyses, and Figures 9 and 10 in the appendix show backscatter electron images of two discrete thorium oxide particles in the minus 200-mesh fraction.

Table 4. Results of Electron Microprobe Spot Analyses of Dusable Park Area B2 Sample

Sample	Particle No.	Particle Composition	ThO ₂ %	Size μ m	Comments
10 by 200 Mesh	1	Thorium Oxide	100	12	Associated with Fe Oxide
	2	REPO ₄ (Monazite)	0	8	In Silicate Agglomerate
	3	REPO ₄ + Th (Monazite)	7.3	25 \times 100	Liberated
	4	REPO ₄ + Th (Monazite)	3.3	3-4	Locked in Quartz
	5	REPO ₄ (Monazite)	0	8	Locked in Quartz
	6	REPO ₄ (Monazite)	0	7 \times 17	Locked in Silicate with FeOx
	7	Thorium Oxide	100	4	Locked in Silicate
	8	Thorium Oxide	100	4 \times 10	Locked in Fe Silicate
Minus 200 Mesh	1	Thorium Oxide	100	6	Liberated
	2	Thorium Oxide	100	2 \times 7	Liberated
	3	Thorium Oxide	100	4	Liberated
	4	Thorium Oxide	100	4	Liberated
	5	Thorium Oxide	100	4 \times 6	Liberated
	6	Thorium Oxide	100	2 \times 5	Liberated
	7	Ca REPO ₄	35	15	Liberated
	8	Thorium Oxide	100	7 \times 15	Liberated
	9	Thorium Oxide	100	5 \times 14	Liberated
	10	Thorium Oxide	100	2 \times 6	Liberated
	11	Thorium Oxide	100	1 \times 4	Liberated
	12	Thorium Oxide	100	4	Liberated
	13	Thorium Oxide	100	1 \times 5	Liberated
	14	Thorium Oxide	100	3 \times 20	Liberated
	15	Thorium Oxide	100	3 \times 9	Liberated
	16	REPO ₄ (Monazite)	0	2 \times 3	Liberated
	17	Thorium Oxide	100	5 \times 14	Liberated

Mr. Tom Gibson
December 12, 2002
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If you have any questions please call.

Sincerely,

Roland Schmidt

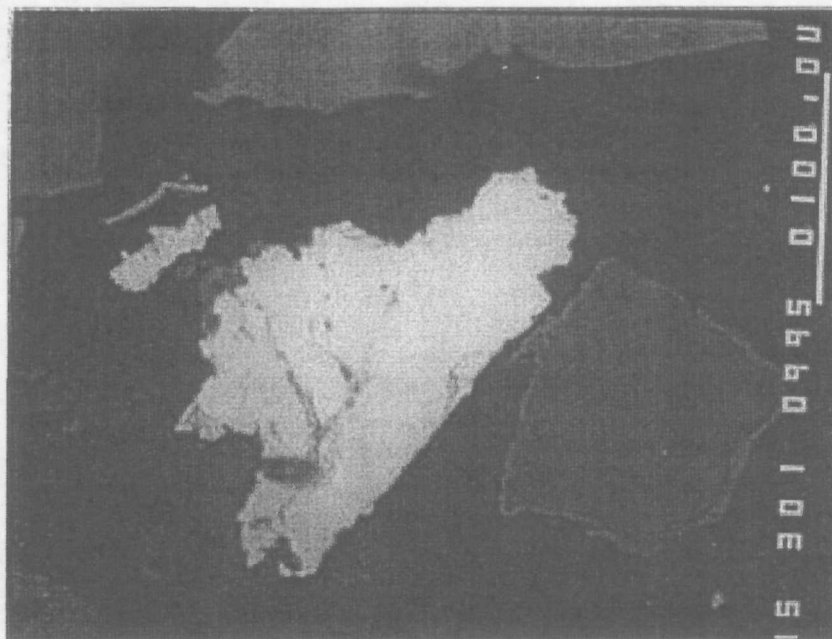
Roland Schmidt
Director, Mineralogical Laboratories

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Enclosures

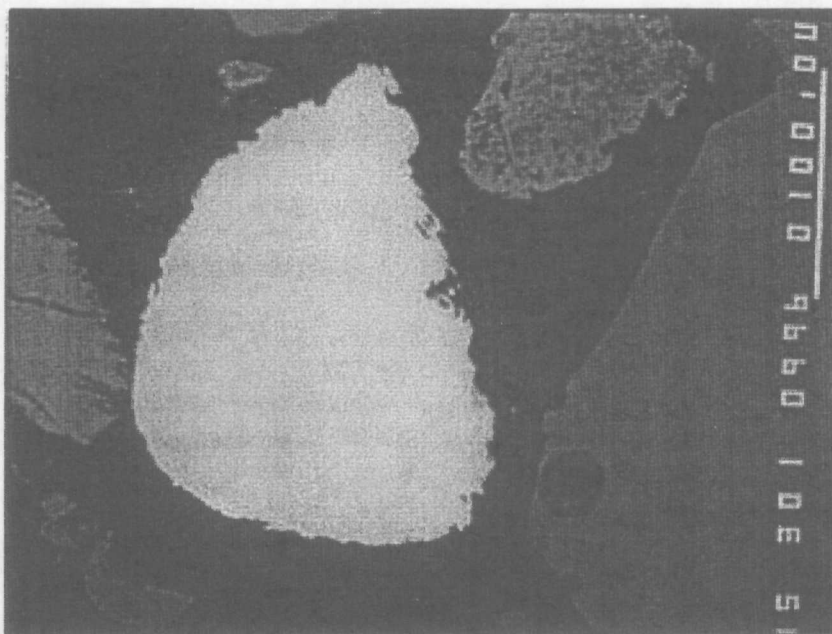
APPENDIX

Figures 1 through 10



White bar = 100 μ m

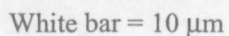
Figure 1. 10 \times 200 Mesh, Particle No. 4



White bar = 100 μ m

Figure 2. 10 \times 200 Mesh, Particle No. 8

Backscatter electron images of angular and rounded, liberated monazite particles (white) in coarse (plus 200 mesh) fraction assaying 12.7 % and 9.7 % ThO_2 , respectively. The particles correspond to particles 4 and 8 in Table 3.



Backscatter photograph showing a particle of iron, calcium, and aluminum silicate (dark gray areas covering most of picture area) with streaky disseminations of complex silicate that have higher iron levels and spotty occurrences of RE phosphate carrying 1 to 2% ThO₂ (lightest spots).

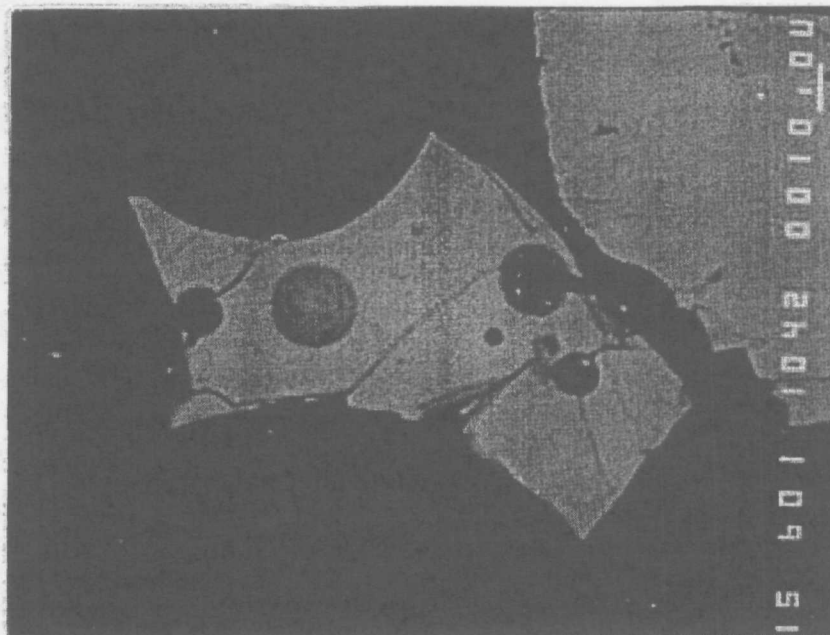
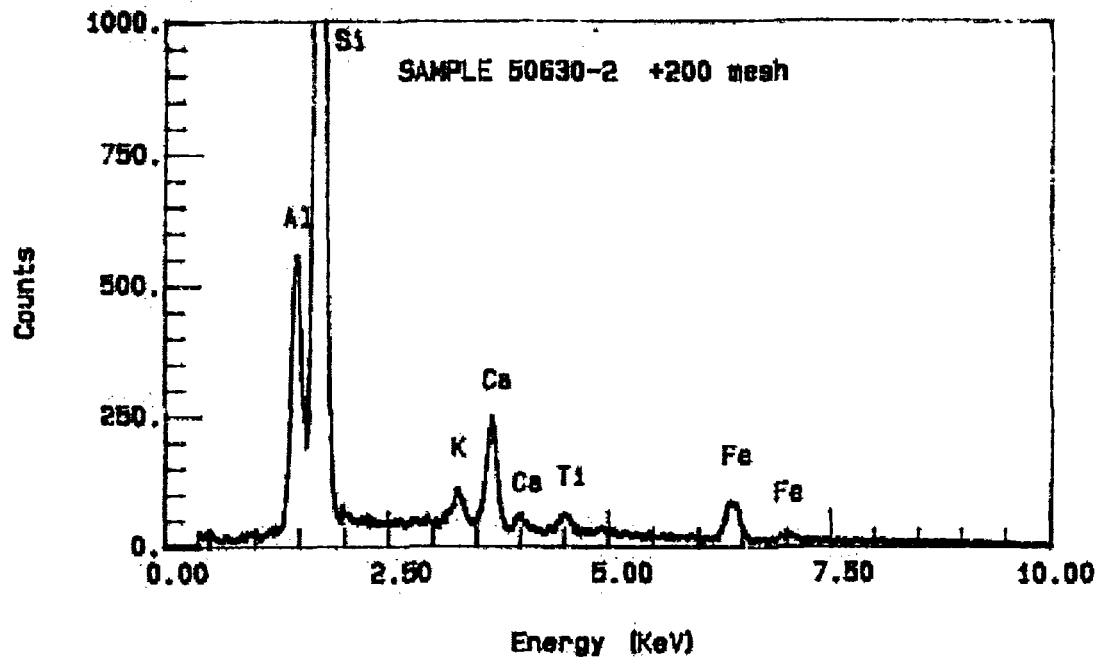


Figure 4. Area C +200 mesh

Weight, %							
Spot	ThO ₂	Al ₂ O ₃	SiO ₂	K ₂ O	CaO	TiO ₂	FeO
1	0.18	18	65	1.2	6.7	1.9	7.3
2	0.16						
3	0.16						
4	0.19						
5	0.19						

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PROJECT 9939



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TASK-BC

SPEC 4

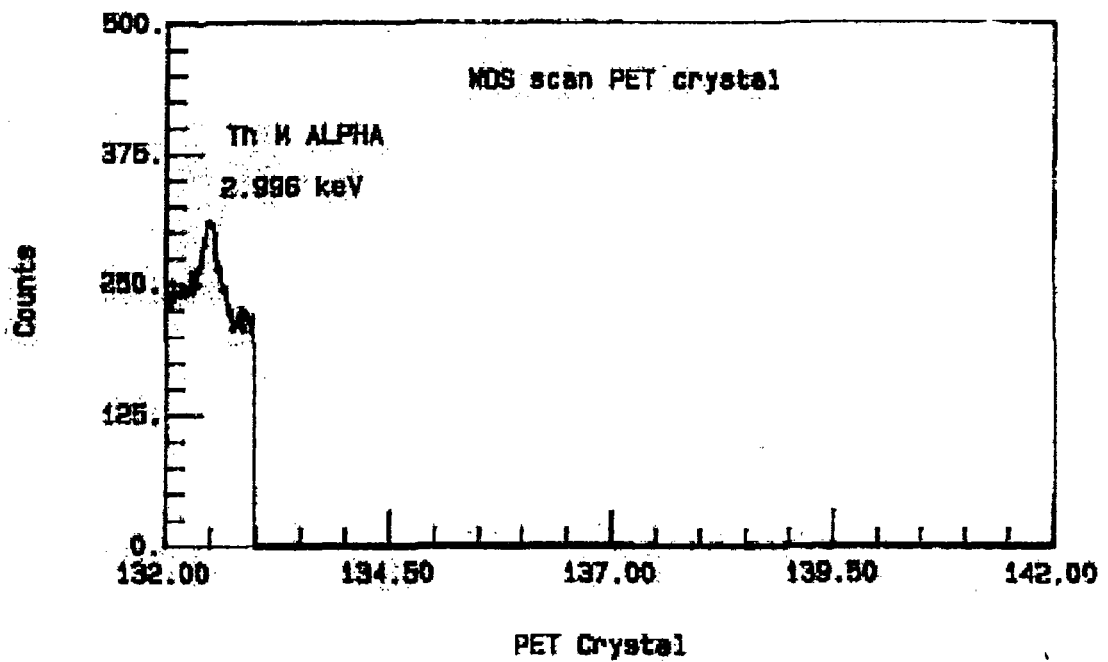


Figure 4a. EDS (top) and WDS (bottom) Showing Thorium Peak for Slag Particle in Figure 4.

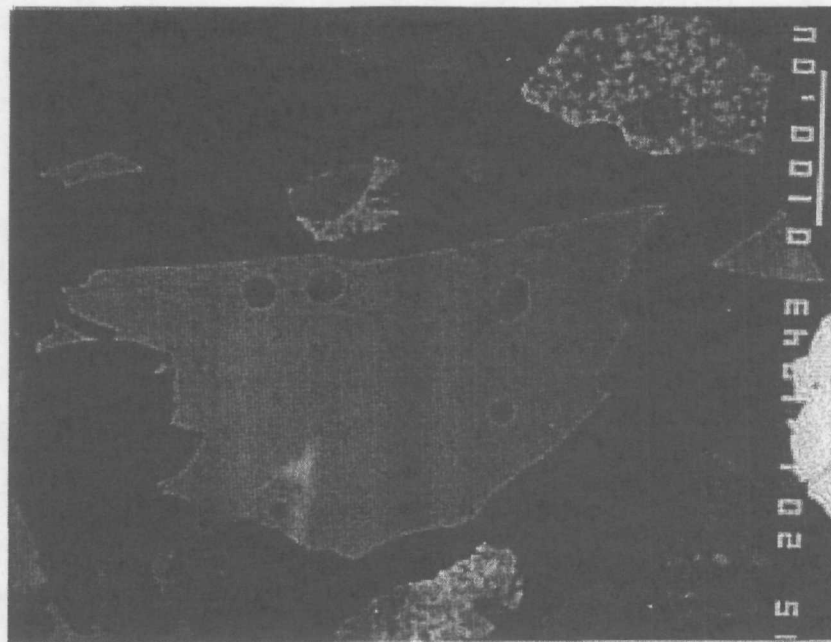


Figure 5. Area C + 200 Mesh

Spot	Weight, %						
	ThO ₂	Al ₂ O ₃	SiO ₂	K ₂ O	CaO	TiO ₂	FeO
1	0.22	17	67	1.3	7.5	1.5	5.7
2	0.16						
3	0.20						
4	0.15						
5	<0.03 ND						
6	<0.03 ND						

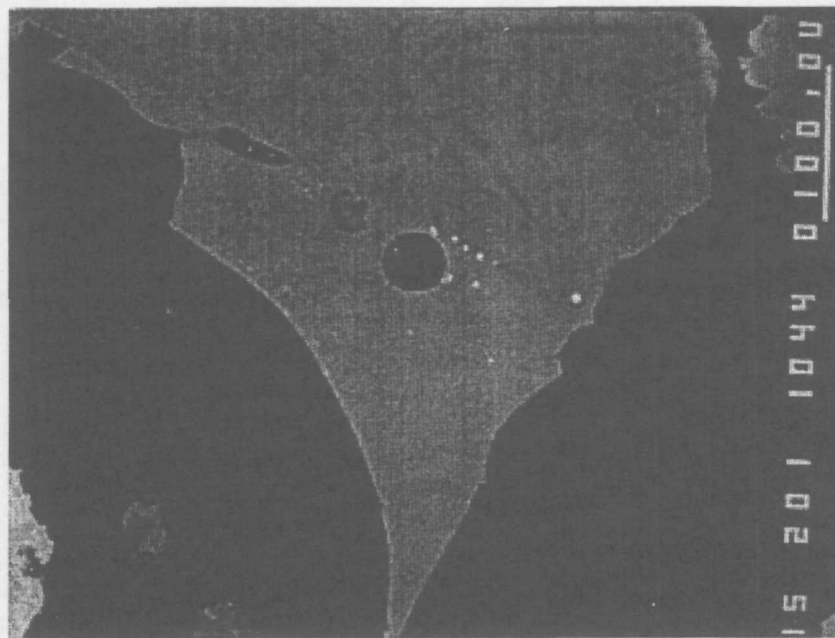


Figure 6. Area C +200 Mesh

Spot	Weight, %						
	ThO ₂	Al ₂ O ₃	SiO ₂	K ₂ O	CaO	TiO ₂	FeO
1-Smooth triangle area	0.20	19	65	1.1	7.5	2.1	5.5
2-Smooth triangle area	0.22						
3-Smooth triangle area	0.18						
4-Mottled area	<0.03 ND						
Mottled area, dark spots		high	? (corundum)				

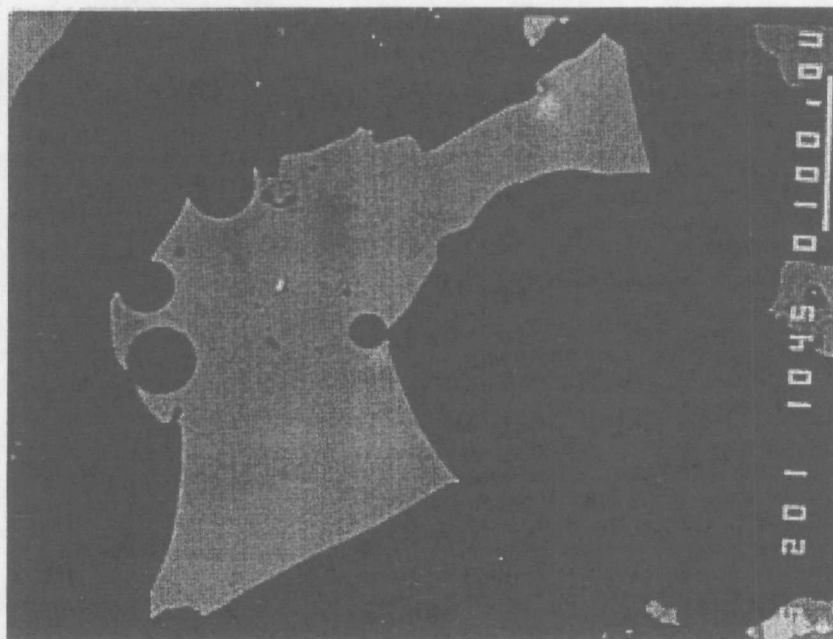
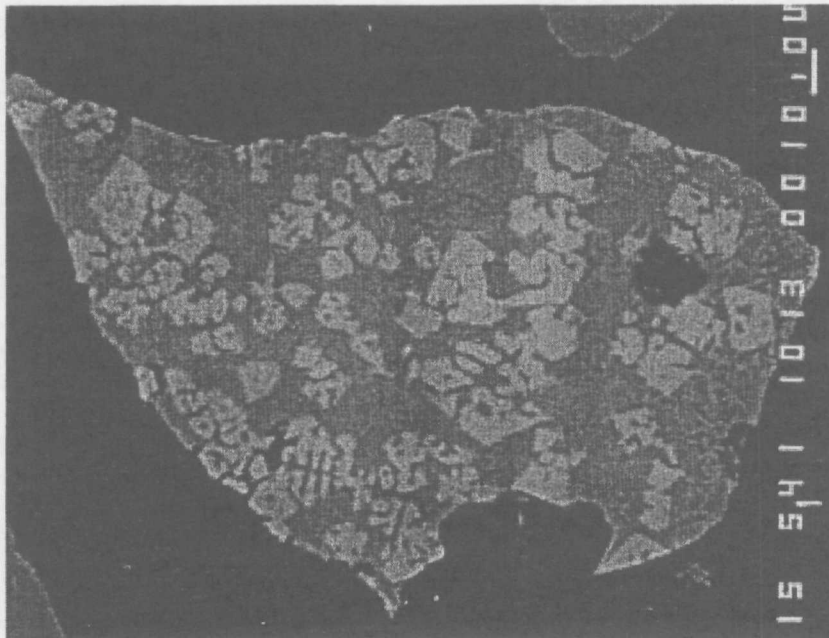


Figure 7. Area C +200 Mesh

Spot	Weight, %						FeO
	ThO ₂	Al ₂ O ₃	SiO ₂	K ₂ O	CaO	TiO ₂	
1	0.16	19	62	1.3	8.9	1.3	7.4
2	0.15						
3	<0.03 ND						
4	<0.03 ND						
5	<0.03 ND						

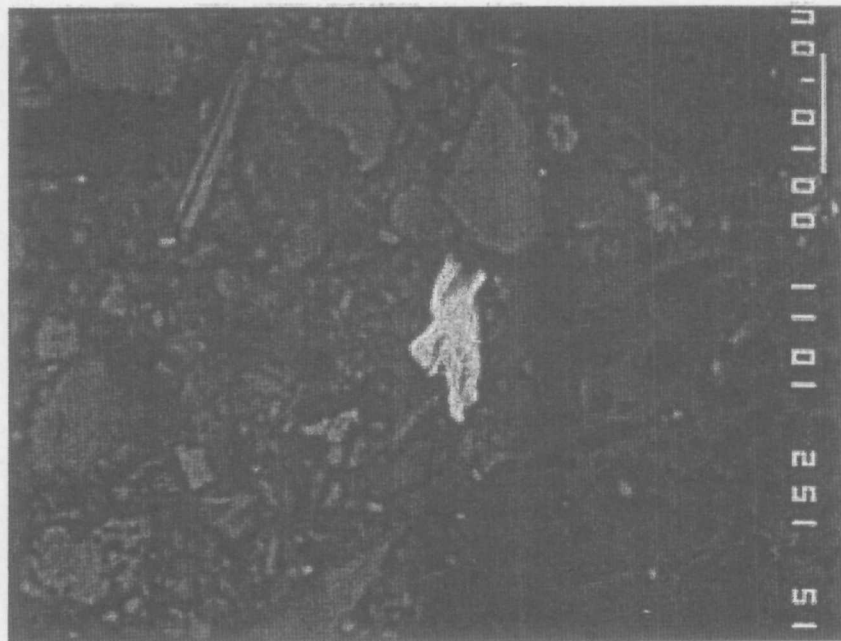
Darker gray area = SiO₂



White bar = 10 μm

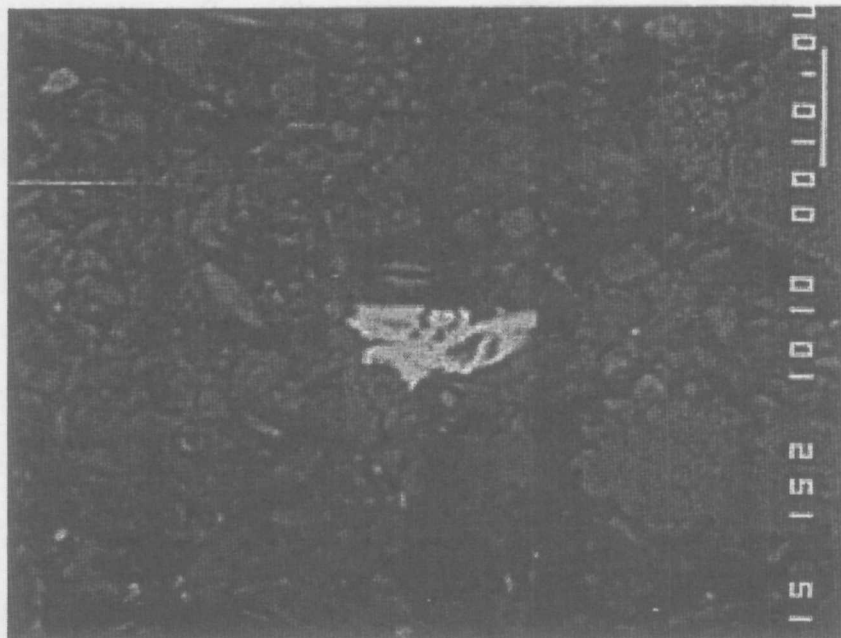
Figure 8. Area C Sample

Backscatter electron image of typical slag or clinker particle in the 10- by 200-mesh fraction showing exsolved iron oxide crystals (white) in a calcium, iron, aluminum silicate matrix. Thorium could not be detected in particles with these characteristics.



White bar = 10 μm

Figure 9. Dusable Park Sample



White bar = 10 μm

Figure 10. Dusable Park Sample

Backscatter electron images illustrating the nature of liberated thorium oxide crystal aggregates in the minus 200-mesh fraction.

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ATTACHMENT B

SUMMARY OF RADIOLOGICAL ANALYSES OF DUSABLE SOIL SAMPLES

Attachment B

Radiologic Analyses of DuSable Samples

Hazen Floatation Samples				Activities in pCi/g		
Sample #	Weight	Sample Description	Dominate Material Types	Ac-228	Pb-214	Total Radium
Area C	18.4	-200 mesh	Slimes	11.9	5.0	16.8
Area C	12.3	14 x 200 mesh, float (1.65)	Coal and organics	2.9	2.4	5.4
Area C	19.9	14 x 200 mesh, float (2.96)	Coal clinker and silicates	4.6	3.5	8.0
Area C	3.1	14 x 200 mesh, sink (2.96)	Mineral sand and iron slag	246.8	35.8	282.6
Area C	11.9	+14 mesh, float (1.65)	Coal and organics	3.4	1.3	4.7
Area C	20.6	+14 mesh, float (2.96)	Coal clinker and silicates	5.3	2.6	7.9
Area C	7.6	+14 mesh, sink (2.96)	Mineral sand and iron slag	< 5.7	28.0	33.7
Area B2	18.0	-200 mesh		29.4	2.0	31.3
Area B2	24.6	+200 mesh		4.3	1.2	5.5

Post Excavation Bulk Samples	Total Radium (Ac-228 + Pb-214) pCi/g			
	KM Samples	EPA Samples	EPA Samples Recount	EPA NAREL Count
	Area	10/4/02	10/7/02	11/7/02
B-1	1.7	1.1	1.1	1.2
B-2	6.8	4.7	4.6	4.7
B-3	5.3	3.5	3.4	3.7
A	4.9	5.3	5.1	5.3
C	11.2	8.0	7.8	8.2

ATTACHMENT C

INTERNET LITERATURE SEARCH

Monazite in West Virginia Coals (www.wvgs.wvnet.edu/www/datastat/te/monazite.htm)

EPA – TENORM Sources (EPA's Radiation Protection Programs: TENORM)

(www.epa.gov/radiation/tenorm/sources.htm)

USGS – Radioactive Elements in Coal and Fly Ash: Abundance, Forms and Environmental Significance (<http://greenwood.cr.usgs.gov/energy/factshts/163-97/FS-163-97.html>)

Y-12 Study on Coal Ash Risks from Exposure (www.em.doe.gov/tie/fall30.html)

Coal Combustion: Nuclear Resource or Danger

(www.ornl.gov/ORNLReview/rev26-34/text/colmain.html)



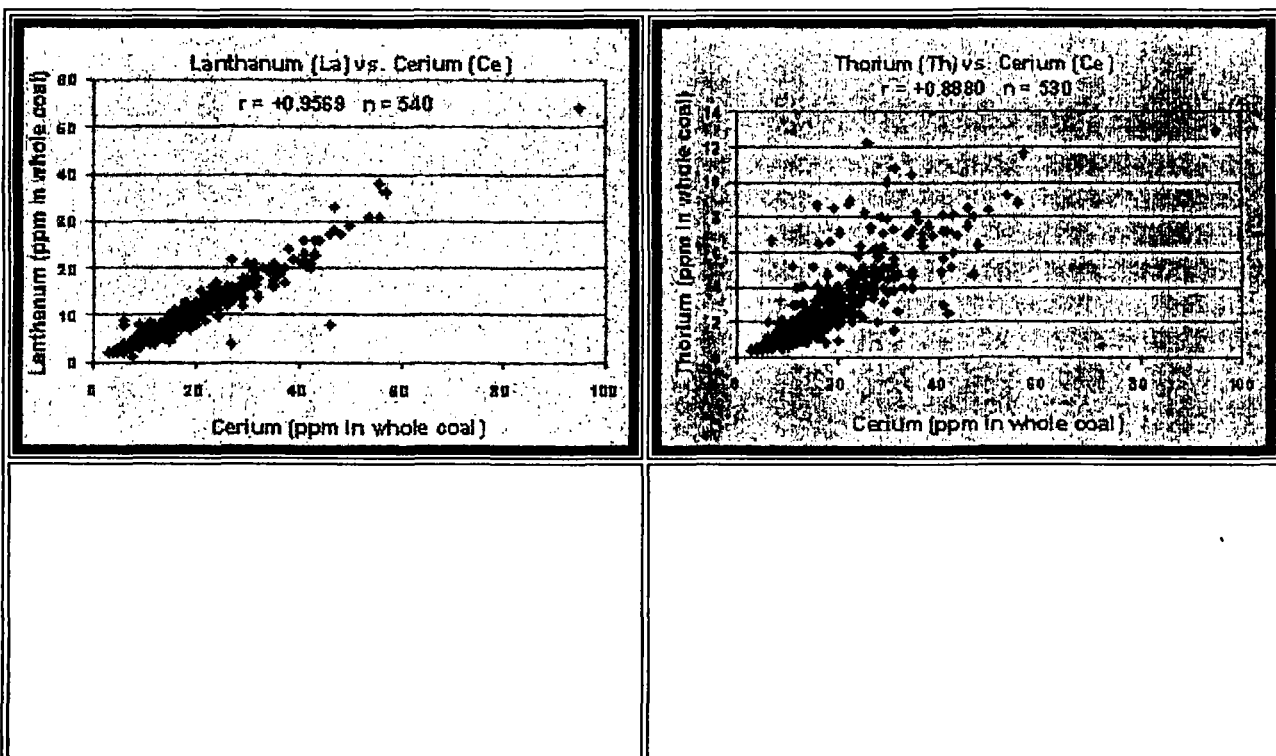
Trace Minerals in West Virginia Coals

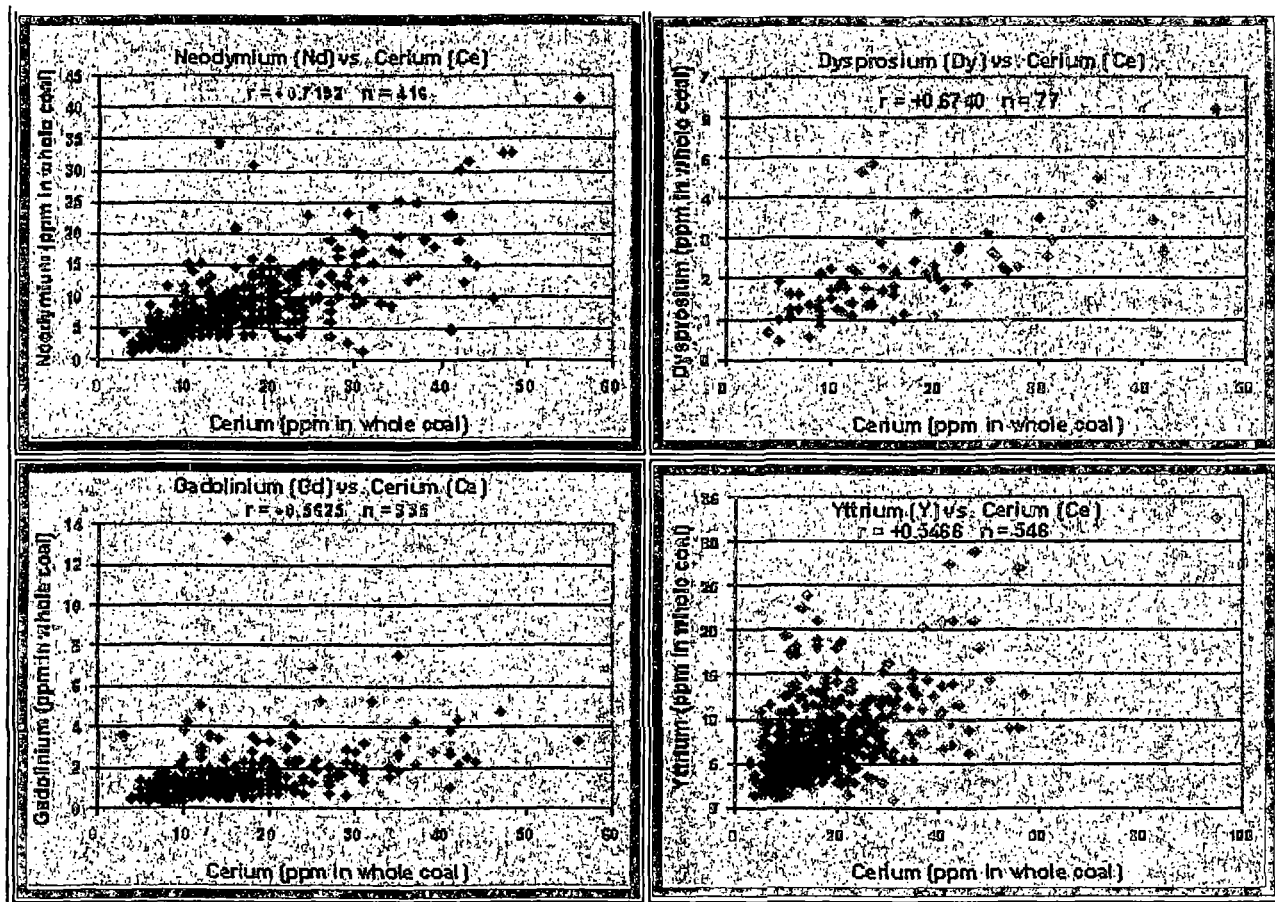


Monazite:

Cerium-Lanthanum-Thorium-Neodymium-Yttrium Phosphate (Ce, La, Th, Nd, Y)PO₄

Monazite is a rare igneous mineral present in granite which weathers free, and because of its great resistance to chemical attack, is concentrated as a detrital mineral in sands. Monazite in coal occurs as micron-size, and smaller, detrital grains introduced into the coal swamp as a windblown or waterborne detrital mineral, and very rarely in volcanic ash falls, and because of its great resistance is unaffected by acids in the swamp. Cerium in coal is primarily a component of the mineral monazite and correlations between Ce and other rare earth elements present in monazite suggest that these elements are also primarily present in monazite. The very high correlation between Ce and La strongly suggests that these two elements are primarily in monazite, and in the 2:1 ratio shown in the graph because of their similar atomic weights. Other trace element components of monazite, Th, Nd, Dy and Gd also correlate with Ce at 6:1 for Ce:Th (= 3.5:1 corrected for differing atomic weights), Ce:Nd = 2:1, Ce:Dy = 10:1 and Ce:Gd also at 10:1. These elements do not correlate with Ce as well and are probably present in other minerals as well. Yttrium displays a bifurcating graph, probably showing its presence in both monazite and xenotime.





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Mining and Resource Extraction

TENORM may be present in mining wastes. These wastes, most significantly from uranium mining, may be generated in large volumes and stored on land near the mine site. The waste rock and soil has little or no practical use. Uranium mine wastes from mines that closed before about 1975 are of particular concern. In many cases, these mines remain unreclaimed today, with the wastes piled near the mine as it was when the mine closed.

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Uranium

The mining of uranium ores by underground, by in-situ leaching, and by surface methods produces large and small amounts of bulk waste material, including excavated top soil, overburden that contains no ore, weakly uranium-enriched waste rock, and subgrade ores, and evaporation pond sludges and scales. These materials typically contain radionuclides of radium, uranium, and thorium.

Materials

Radiation Level [pCi/g]

low average high

Uranium Mining Overburden

low

Uranium In-Situ Leachate
Evaporation Pond

3 30

low hundreds

Solids

300

3000



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Fertilizer Production

The production of phosphates for fertilizer generates wastes in very large volumes that are stored in huge piles called "stacks" that cover hundreds of acres in Florida and other phosphate-processing states. These radioactive materials contain radium and other radionuclides and create large amounts of radon. EPA and state agencies have regulations controlling these wastes. In addition, the state of Florida has created an independent state research agency charged with investigating ways to minimize adverse environmental impacts of the phosphate industry.

Materials	Radiation Level [pCi/g]		
	low	average	high
Phosphate Ore (Florida)	7	17.3-39.5	6.2-53.5
Phosphogypsum	7.3	11.7-24.5	36.7
Phosphate Fertilizer	0.5	5.7	21

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Aluminum

Waste muds created by the extraction of alumina from its ore, bauxite, may contain low levels of radioactivity, usually from uranium, thorium, radium, and their radioactive decay products

Materials

Materials	Radiation Level [pCi/g]		
	low	average	high
Ore (Bauxite)	4.4	NA	7.4
Product		0.23	
Production Wastes	NA	3.9-5.6	NA

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Copper Waste Rock

Mining and extraction of copper by common surface or underground methods can concentrate or expose uranium,

thorium, and radium in waste rock. Another extraction method, known as "in-situ" leaching, can transport uranium and thorium into groundwater or surface water at the site. In this method, rather than removing soil and rock to reach the copper deposit, liquids containing chemicals are allowed to seep through copper-bearing rocks and dissolve the copper. It also dissolves radionuclides that may be in the soil and rock. The liquids are captured and the copper is recovered, leaving the radionuclides. Some of the liquids remain and may contaminate water in the area. In-situ leaching may also be used on tailings (waste rock).

Wastes

Radiation Level [pCi/g]			
	low	average	high
Copper Waste Rock	0.7	12	82.6



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Gold and Silver

While few studies have been done on these ores, some western mines produced uranium as a secondary product when extracting precious metals. Pitchblende (a naturally occurring material containing low concentrations of uranium) has been found in the same ores as gold and silver. Waste rock from some of these mines may be radioactive.

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Rare Earths

Rare earths are a group of elements that have electrical properties that make them useful in electronics and electrical applications. Lanthanides and yttrium are recovered primarily from ores and minerals that naturally contain uranium and thorium. As a result, the waste rock and sludges from the extraction of rare earths also contain these radionuclides.

Materials	Radiation Level [pCi/g]		
	low	average	high
Rare Earths(Monazite, Xenotime, Bastnasite)	5.7		3224



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Titanium Ores

Uranium, thorium, and radium commonly occur in titanium

ore and monazite occurs in sands from which the titanium is extracted. As a result, the mineral sludges, dusts, and sands from the extraction process may be radioactive.

Materials	Radiation Level [pCi/g]		
	low	average	high
Titanium Ores		8.0	24.5
Rutile	3.9	19.7	NA
Ilmenite	NA	5.7	
Wastes	3.9	12	45



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Zircon

Zircon is naturally radioactive, containing small amounts of uranium, thorium and radium in its crystalline structure. It is also mined from deposits containing other radioactive minerals such as monazite.

Materials	Radiation Level [pCi/g]		
	low	average	high
Zircon		68	
Wastes	87		1300



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Energy Production Wastes

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Coal and Coal Ash

Coal contains trace quantities of the naturally occurring radionuclides of uranium, thorium, and potassium as well as their radioactive decay products. When coal is burned, minerals including most of the radionuclides do not burn and as a result are concentrated in the ash.

Wastes	Radiation Level [pCi/g]		
	low	average	high
Bottom Ash	1.6	3.5-4.6	7.7
Fly Ash	2	5.8	9.7


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Geothermal Energy Waste Scales

Using geothermal energy, requires drilling deep holes (boreholes) and inserting pipes for pumping high-temperature fluids from the ground. The rocks that contain the high-temperature fluids may also contain minerals, which tend to form a scale inside the pipes and production equipment. If the rocks also contain radionuclides, such as radium, the mineral scale, production sludges, and waste water will contain TENORM.

Wastes	Radiation Level [pCi/g]		
	low	average	high
Geothermal Energy Waste Scales	10	132	254


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Petroleum (Oil and Gas)

The rocks that contain oil and gas deposits often contain water as well. The water will dissolve minerals and radionuclides, such as radium, that are in the rocks. As a result, radium and its radioactive decay products become concentrated in production wastes. Wastes include: pipe scale that tends to form inside oil and gas production pipes and equipment, large volumes of waste water, and sludges that accumulate in tanks or pits.

Wastes	Radiation Level [pCi/g]		
	low	average	high
Produced Water [pCi/l]	0.1	NA	9,000
Pipe/Tank Scale	<0.25	<200	>100,000

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Water and Waste Treatment Residues

Water Treatment

Since water comes from streams, lakes, reservoirs and aquifers, it contains varying levels of naturally occurring radioactivity derived from surrounding rocks and sediments. Wastes from municipal water treatment plants receiving this water may concentrate some amounts of this radioactivity, even if the treatment systems were not originally designed to remove it.

Wastes	Radiation Level [pCi/g]		
	low	average	high
Treatment Sludge [pCi/l]	1.3	11	11,686
Treatment Plant Filters		40,000	



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Products Containing TENORM

Some TENORM may be found in certain consumer products. For example, zircon contains minute quantities of uranium and thorium, and is widely used as a glaze for ceramics and metal molds.

The EPA and others working on the problem have identified many sources of TENORM. Identifying sources and determining the potential risks from them remains a major focus of our work.

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URL: <http://www.epa.gov/radiation/tenorm/sources.htm>

Radioactive Elements in Coal and Fly Ash: Abundance, Forms, and Environmental Significance

U.S. Geological Survey Fact Sheet FS-163-97

October, 1997

Introduction

Coal is largely composed of organic matter, but it is the inorganic matter in coal—minerals and trace elements—that have been cited as possible causes of health, environmental, and technological problems associated with the use of coal. Some trace elements in coal are naturally radioactive. These radioactive elements include uranium (U), thorium (Th), and their numerous decay products, including radium (Ra) and radon (Rn). Although these elements are less chemically toxic than other coal constituents such as arsenic, selenium, or mercury, questions have been raised concerning possible risk from radiation. In order to accurately address these questions and to predict the mobility of radioactive elements during the coal fuel-cycle, it is important to determine the concentration, distribution, and form of radioactive elements in coal and fly ash.

Abundance of Radioactive Elements in Coal and Fly Ash

Assessment of the radiation exposure from coal burning is critically dependent on the concentration of radioactive elements in coal and in the fly ash that remains after combustion. Data for uranium and thorium content in coal is available from the U.S. Geological Survey (USGS), which maintains the largest database of information on the chemical composition of U.S. coal. This database is searchable on the World Wide Web at: <http://energy.er.usgs.gov/products/databases/CoalQual/intro.htm>. Figure 1 displays the frequency distribution of uranium concentration for approximately 2,000 coal samples from the Western United States and approximately 300 coals from the Illinois Basin. In the majority of samples, concentrations of uranium fall in the range from slightly below 1 to 4 parts per million (ppm). Similar uranium concentrations are found in a variety of common rocks and soils, as indicated in figure 2. Coals with more than 20 ppm uranium are rare in the United States. Thorium concentrations in coal fall within a similar 1–4 ppm range, compared to an average crustal abundance of approximately 10 ppm. Coals with more than 20 ppm thorium are extremely rare.

During coal combustion most of the uranium, thorium, and their decay products are released from the original coal matrix and are distributed between the gas

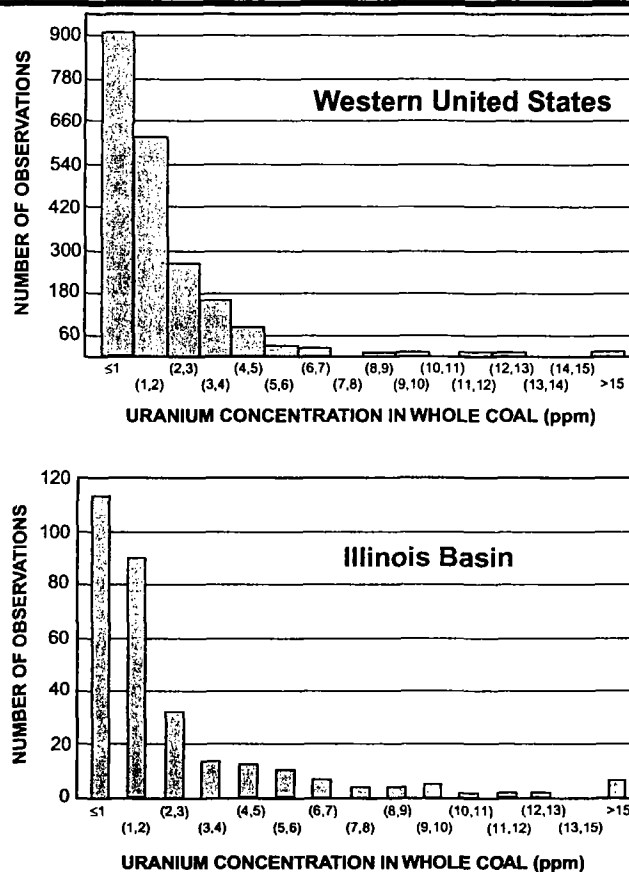


Figure 1. Distribution of uranium concentration in coal from two areas of the United States.

phase and solid combustion products. The partitioning between gas and solid is controlled by the volatility and chemistry of the individual elements. Virtually 100 percent of the radon gas present in feed coal is transferred to the gas phase and is lost in stack emissions. In contrast, less volatile elements such as thorium, uranium, and the majority of their decay products are almost entirely retained in the solid combustion wastes. Modern power plants can recover greater than 99.5 percent of the solid combustion wastes. The average ash yield of coal burned in the United States is approximately 10 weight percent. Therefore, the concentration of most radioactive elements in solid combustion wastes will be approximately 10 times the concentration in the original coal. Figure 2 illustrates that the uranium concentration of most fly ash (10 to 30 ppm) is still in the range found in some granitic rocks, phosphate rocks, and shales. For example,

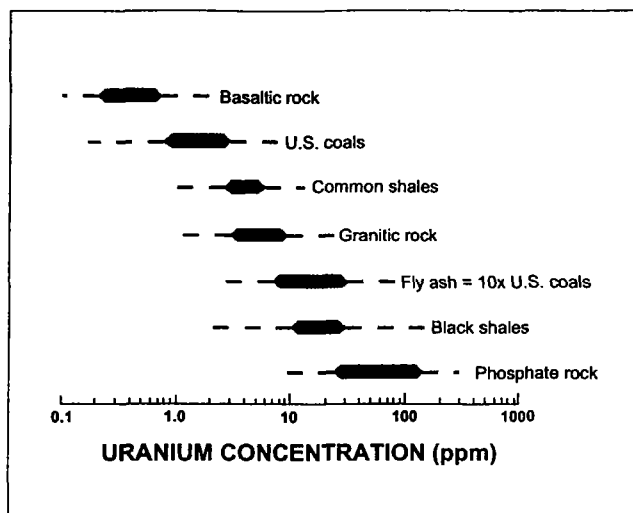


Figure 2. Typical range of uranium concentration in coal, fly ash, and a variety of common rocks.

the Chattanooga Shale that occurs in a large portion of the Southeastern United States contains between 10 and 85 ppm U.

Forms of Occurrence of Radioactive Elements in Coal and Fly Ash

The USGS has a current research project to investigate the distribution and modes of occurrence (chemical form) of trace elements in coal and coal combustion products. The approach typically involves (1) ultra sensitive chemical or radiometric analyses of particles separated on the basis of size, density, mineral or magnetic properties, (2) analysis of chemical extracts that selectively attack certain components of coal or fly ash, (3) direct observation and microbeam analysis of very small areas or grains, and (4) radiographic techniques that identify the location and abundance of radioactive elements.

Most thorium in coal is contained in common phosphate minerals such as monazite or apatite. In contrast, uranium is found in both the mineral and organic fractions of coal. Some uranium may be added slowly over geologic time because organic matter can extract dissolved uranium from ground water. In fly ash, the uranium is more concentrated in the finer sized particles. If during coal combustion some uranium is concentrated on ash surfaces as a condensate, then this surface-bound uranium is potentially more susceptible to leaching. However, no obvious evidence of surface enrichment of uranium has been found in the hundreds of fly ash particles examined by USGS researchers.

The above observation is based on the use of fis-

sion-track radiography, a sophisticated technique for observing the distribution of uranium in particles as small as 0.001 centimeter in diameter. Figure 3 includes a photograph of a hollow glassy sphere of fly ash and its corresponding fission track image. The diameter of this relatively large glassy sphere is approximately 0.01 cm. The distribution and concentration of uranium are indicated by fission tracks, which appear as dark linear features in the radiograph. Additional images produced by USGS researchers from a variety of fly ash particles confirm the preferential location of uranium within the glassy component of fly ash particles.

Health and Environmental Impact of Radioactive Elements Associated With Coal Utilization

Radioactive elements from coal and fly ash may come in contact with the general public when they are dispersed in air and water or are included in commercial products that contain fly ash.

The radiation hazard from airborne emissions of coal-fired power plants was evaluated in a series of studies conducted from 1975-1985. These studies concluded that the maximum radiation dose to an individual living within 1 km of a modern power plant is equivalent to a minor, perhaps 1 to 5 percent, increase above the radiation from the natural environment. For the average citizen, the radiation dose from coal burning is considerably less. Components of the radiation environment that impact the U.S. population are illustrated in figure 4. Natural sources account for the majority (82 percent) of radiation. Man-made sources of radiation are dominated by medical X-rays (11 percent). On this plot, the average population dose attributed to coal burning is included under the consumer products category and is much less than 1 percent of the total dose.

Fly ash is commonly used as an additive to concrete building products, but the radioactivity of typical fly ash is not significantly different from that of more conventional concrete additives or other building materials such as granite or red brick. One extreme calculation that assumed high proportions of fly-ash-rich concrete in a residence suggested a dose enhancement, compared to normal concrete, of 3 percent of the natural environmental radiation.

Another consideration is that low-density, fly-ash-rich concrete products may be a source of radon gas. Direct measurement of this contribution to indoor radon is complicated by the much larger contribution from underlying soil and rock (see fig. 4). The emanation of radon gas from fly ash is less than from natural soil of

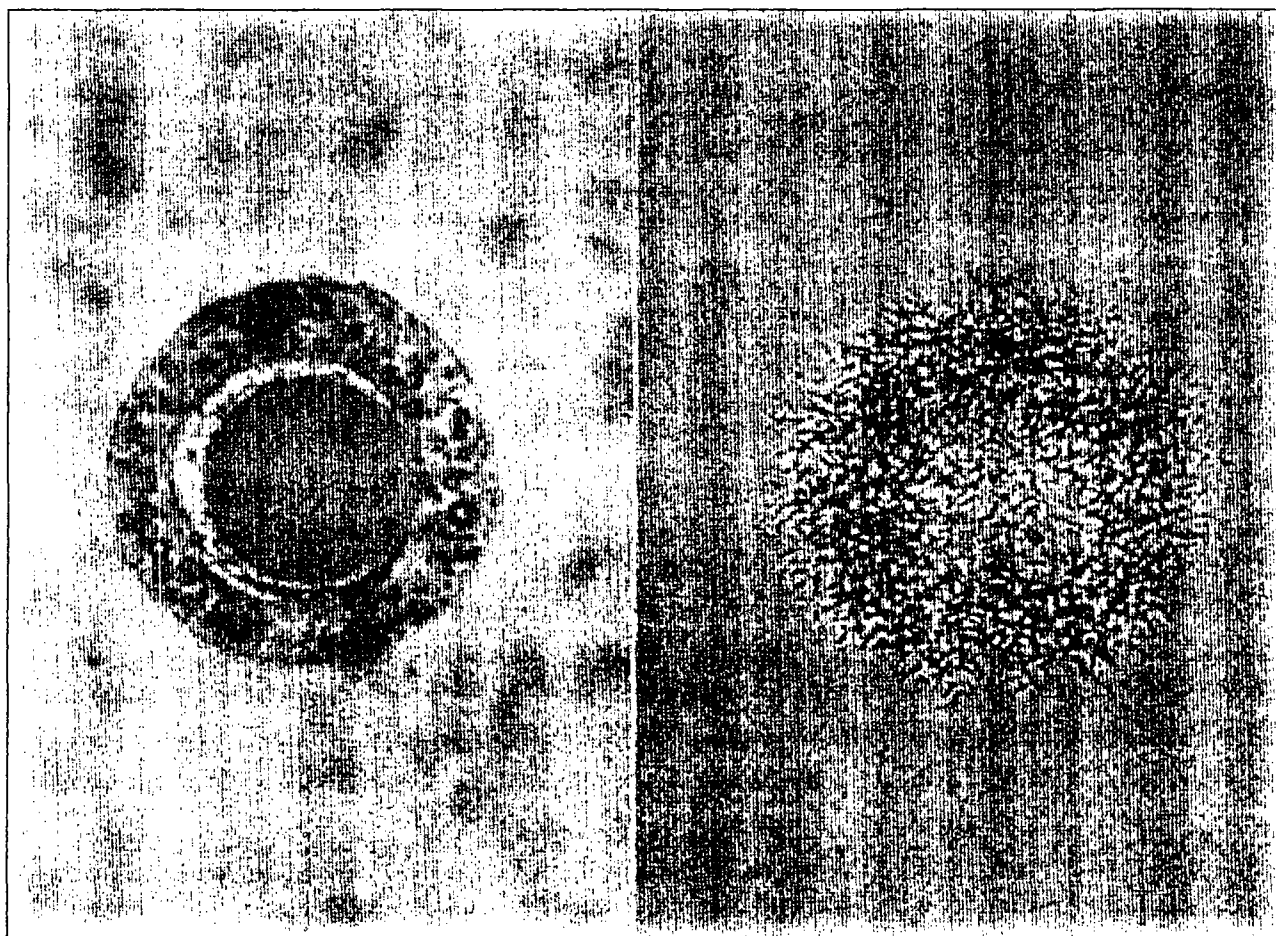


Figure 3. Photograph (left) of a hollow glassy fly ash particle (0.01 cm diameter) and its fission track radiograph (right). Uranium distribution and concentration are indicated by the location and density of dark linear fission tracks in the radiograph.

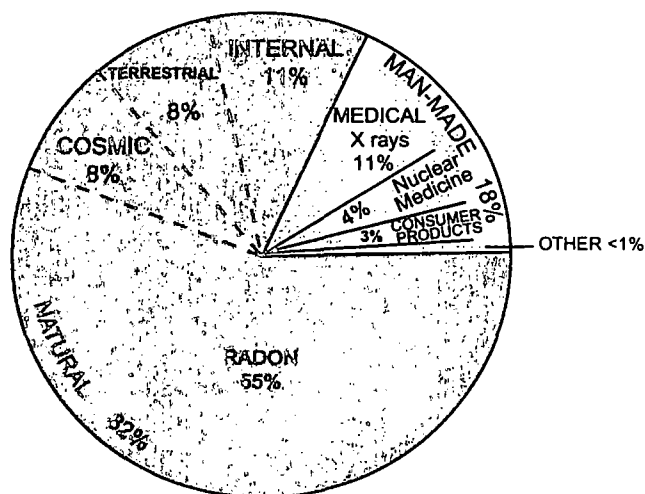


Figure 4. Percentage contribution of various radiation sources to the total average radiation dose to the U.S. population.

similar uranium content. Present calculations indicate that concrete building products of all types contribute less than 10 percent of the total indoor radon.

Approximately three-fourths of the annual production of fly ash is destined for disposal in engineered surface impoundments and landfills, or in abandoned mines and quarries. The primary environmental concern associated with these disposal sites is the potential for ground-water contamination. Standardized tests of the leachability of toxic trace elements such as arsenic, selenium, lead, and mercury from fly ash show that the amounts dissolved are sufficiently low to justify regulatory classification of fly ash as nonhazardous solid waste. Maximum allowable concentrations under these standardized tests are 100 times drinking water standards, but these concentration limits are rarely approached in leachates of fly ash.

The leachability of radioactive elements from fly ash has relevance in view of the U.S. Environmental Protection Agency (USEPA) drinking water standard for dissolved radium (5 picocuries per liter) and the proposed addition of drinking water standards for uranium and radon by

the year 2000. Previous studies of radioelement mobility in the environment, and in particular, in the vicinity of uranium mines and mills, provide a basis for predicting which chemical conditions are likely to influence leachability of uranium, barium (a chemical analog for radium), and thorium from fly ash. For example, leachability of radioactive elements is critically influenced by the pH that results from reaction of water with fly ash. Extremes of either acidity ($\text{pH} < 4$) or alkalinity ($\text{pH} > 8$) can enhance solubility of radioactive elements. Acidic solutions attack a variety of mineral phases that are found in fly ash. However, neutralization of acid solutions by subsequent reaction with natural rock or soil promotes precipitation or sorption of many dissolved elements including uranium, thorium, and many of their decay products. Highly alkaline solutions promote dissolution of the glassy components of fly ash that are an identified host of uranium; this can, in particular, increase uranium solubility as uranium-carbonate species. Fortunately, most leachates of fly ash are rich in dissolved sulfate, and this minimizes the solubility of barium (and radium), which form highly insoluble sulfates.

Direct measurements of dissolved uranium and radium in water that has contacted fly ash are limited to a small number of laboratory leaching studies, including some by USGS researchers, and sparse data for natural water near some ash disposal sites. These preliminary results indicate that concentrations are typically below the current drinking water standard for radium (5 picocuries per liter) or the initially proposed drinking water standard for uranium of 20 parts per billion (ppb).

Summary

Radioactive elements in coal and fly ash should not be sources of alarm. The vast majority of coal and the majority of fly ash are not significantly enriched in radioactive elements, or in associated radioactivity, compared to common soils or rocks. This observation provides a useful geologic perspective for addressing societal concerns regarding possible radiation and radon hazard.

The location and form of radioactive elements in fly ash determine the availability of elements for leaching during ash utilization or disposal. Existing measurements of uranium distribution in fly ash particles indicate a uniform distribution of uranium throughout the glassy particles. The apparent absence of abundant, surface-bound, relatively available uranium suggests that the rate of release of uranium is dominantly controlled by the relatively slow dissolution of host ash particles.

Previous studies of dissolved radioelements in the environment, and existing knowledge of the chemical properties of uranium and radium can be used to predict the most important chemical controls, such as pH, on solubility of uranium and radium when fly ash interacts with water. Limited measurements of dissolved uranium and radium in water leachates of fly ash and in natural water from some ash disposal sites indicate that dissolved concentrations of these radioactive elements are below levels of human health concern.

Suggested Reading:

- Tadmor, J., 1986, Radioactivity from coal-fired power plants: A review: *Journal of Environmental Radioactivity*, v. 4, p. 177-204.
- Cothern, C.R., and Smith, J.E., Jr., 1987, *Environmental Radon*: New York, Plenum Press, 363 p.
- Ionizing radiation exposure of the population of the United States, 1987: Bethesda, Md., National Council on Radiation Protection and Measurements, Report 93, 87 p.
- Swaine, D.J., 1990, *Trace Elements in Coal*: London, Butterworths, 278 p.
- Swaine, D.J., and Goodarzi, F., 1997, *Environmental Aspects of Trace Elements in Coal*: Dordrecht, Kluwer Academic Publishers, 312 p.



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Y-12 Study on Coal Ash Risks from Exposure

Coal ash from combustion in coal-fired steam plants is a common high-volume industrial waste in the United States. Because the Oak Ridge Reservation is currently listed as a National Priorities List site, DOE was required to analyze coal ash to ensure it poses no potential threat to the public or the environment. The analysis was done as part of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) remedial investigation for the Y-12 Plant Filled Coal Ash Pond project. The evaluation showed exposure to naturally occurring constituents in coal ash can present unacceptable risks to human health and the environment.

Chemical analyses of Y-12 Plant coal ash indicated constituents and concentrations typical of coal ash from combustion of coals mined in the eastern United States. Risks to human health from exposure to these naturally occurring constituents in coal ash were evaluated for two land-use scenarios: future residential and current trespasser. Standard CERCLA risk assessment guidance was used to demonstrate that human health risks (primarily from exposure to thorium and arsenic in the coal ash) exceeded the Environmental Protection Agency's (EPA's) action levels of carcinogenic risks (risk greater than or equal to 1E-04) and noncarcinogenic hazards (hazard quotient greater than or equal to 1) for the residential land use. Risks from gamma exposure to thorium in the ash were identified as within the EPA's target risk range (risks between 1E-06 and 1E-04) for the trespasser scenario.

The ecological risk assessment indicated adverse effects to biota from exposure to various metals (primarily selenium and arsenic) in the coal ash. The high levels of sodium in the coal ash were particularly attractive to deer, enhancing their consumption of ash and increasing their risk from exposure to the metallic constituents.

For more information, contact B. D. Nourse/Lockheed Martin Energy Systems, Inc., at (423) 241-2369.

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About This Document
Posted 12/28/1995 (mhp)

Coal Combustion: Nuclear Resource or Danger

By Alex Gabbard



Alex Gabbard at the coal pile for ORNL's steam plant.

Over the past few decades, the American public has become increasingly wary of nuclear power because of concern about radiation releases from normal plant operations, plant accidents, and nuclear waste. Except for Chernobyl and other nuclear accidents, releases have been found to be almost undetectable in comparison with natural background radiation. Another concern has been the cost of producing electricity at nuclear plants. It has increased largely for two reasons: compliance with stringent government regulations that restrict releases of radioactive substances from nuclear facilities into the environment and construction delays as a result of public opposition.

Americans living near coal-fired power plants are exposed to higher radiation doses than those living near nuclear power plants that meet government regulations

Partly because of these concerns about radioactivity and the cost of containing it, the American public and electric utilities have preferred coal combustion as a power source. Today 52% of the capacity for generating electricity in the United States is fueled by coal, compared with 14.8% for nuclear energy. Although there are economic justifications for this preference, it is surprising for two reasons. First, coal combustion produces carbon dioxide and other greenhouse gases that are suspected to cause climatic warming, and it is a source of sulfur oxides and nitrogen oxides, which are harmful to human health and may be largely responsible for acid rain. Second, although not as well known, releases from coal combustion contain naturally occurring radioactive materials--mainly, uranium and thorium.

Former ORNL researchers J. P. McBride, R. E. Moore, J. P. Witherspoon, and R. E. Blanco made this point in their article "Radiological Impact of Airborne Effluents of Coal and Nuclear Plants" in the December 8, 1978, issue of Science magazine. They concluded that Americans living near coal-fired power plants are exposed to higher radiation doses than those living near nuclear power plants that meet government regulations. This ironic situation remains true today and is addressed in this article.

The fact that coal-fired power plants throughout the world are the major sources of radioactive materials released to the environment has several implications. It suggests that coal combustion is more hazardous to health than nuclear power and that it adds to the background radiation burden even more than does nuclear power. It also suggests that if radiation emissions from coal plants were regulated, their capital and operating costs would increase, making coal-fired power less economically competitive.

Finally, radioactive elements released in coal ash and exhaust produced by coal combustion contain fissionable fuels and much larger quantities of fertile materials that can be bred into fuels by absorption of neutrons, including those generated in the air by bombardment of oxygen, nitrogen, and other nuclei with cosmic rays; such fissionable and fertile materials can be recovered from coal ash using known technologies. These nuclear materials have growing value to private concerns and governments that may want to market them for fueling nuclear power plants. However, they are also available to those interested in accumulating material for nuclear weapons. A solution to this potential problem may be to encourage electric utilities to process coal ash and use new trapping technologies on coal combustion exhaust to isolate and collect valuable metals, such as iron and aluminum, and available nuclear fuels.

Makeup of Coal and Ash

Coal is one of the most impure of fuels. Its impurities range from trace quantities of many metals, including uranium and thorium, to much larger quantities of aluminum and iron to still larger quantities of impurities such as sulfur. Products of coal combustion include the oxides of carbon, nitrogen, and sulfur; carcinogenic and mutagenic substances; and recoverable minerals of commercial value, including nuclear fuels naturally occurring in coal.

The amount of thorium contained in coal is about 2.5 times greater than the amount of uranium

Coal ash is composed primarily of oxides of silicon, aluminum, iron, calcium, magnesium, titanium, sodium, potassium, arsenic, mercury, and sulfur plus small quantities of uranium and thorium. Fly ash is primarily composed of non-combustible silicon compounds (glass) melted during combustion. Tiny glass spheres form the bulk of the fly ash.

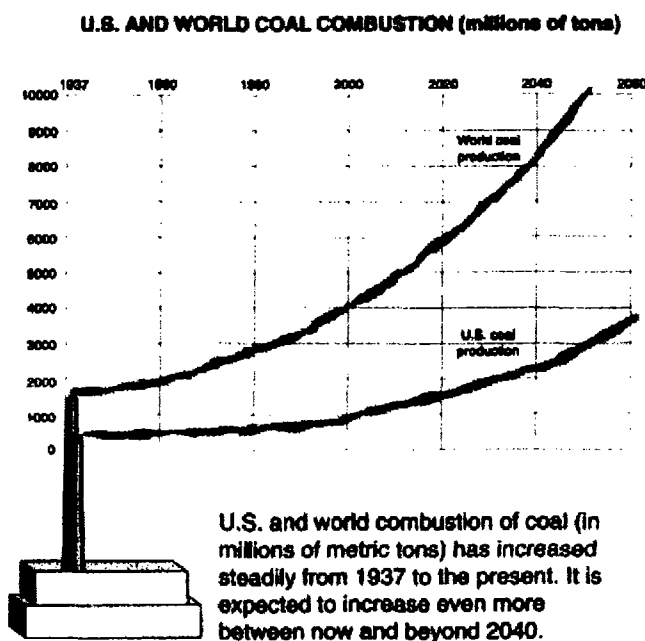
Since the 1960s particulate precipitators have been used by U.S. coal-fired power plants to retain significant amounts of fly ash rather than letting it escape to the atmosphere. When functioning properly, these precipitators are approximately 99.5% efficient. Utilities also collect furnace ash, cinders, and slag, which are kept in cinder piles or deposited in ash ponds on coal-plant sites along with the captured fly ash.

Trace quantities of uranium in coal range from less than 1 part per million (ppm) in some samples to around 10 ppm in others. Generally, the amount of thorium contained in coal is about 2.5 times greater than the amount of uranium. For a large number of coal samples, according to Environmental Protection Agency figures released in 1984, average values of uranium and thorium content have been determined to be 1.3 ppm and 3.2 ppm, respectively. Using these values along with reported consumption and projected consumption of coal by utilities provides a means of calculating the amounts of potentially recoverable breedable and fissionable elements (see sidebar). The concentration of fissionable uranium-235 (the current fuel for nuclear power plants) has been established to be 0.71% of uranium content.

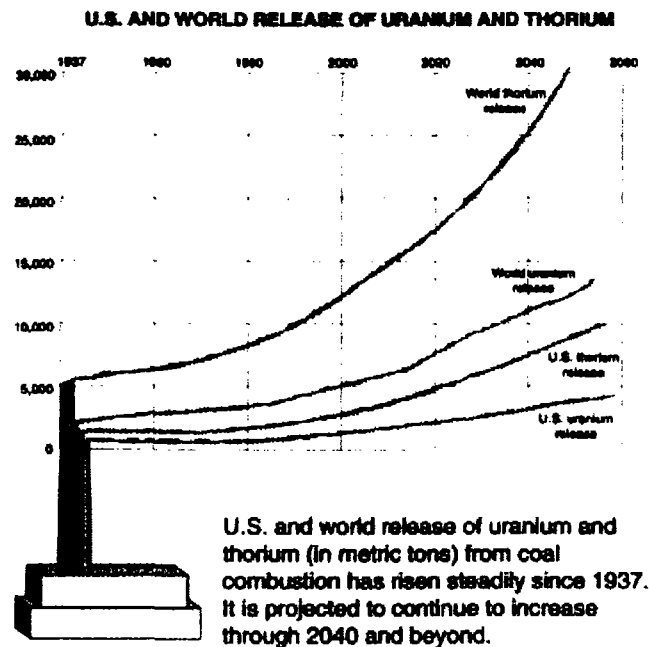
Uranium and Thorium in Coal and Coal Ash

As population increases worldwide, coal combustion continues to be the dominant fuel source for electricity. Fossil fuels' share has decreased from 76.5% in 1970 to 66.3% in 1990, while nuclear energy's share in the worldwide electricity pie has climbed from 1.6% in 1970 to 17.4% in 1990. Although U.S. population growth is slower than worldwide growth, per capita consumption of energy in this country is among the world's highest. To meet the growing demand for electricity, the U.S. utility industry has continually expanded generating capacity. Thirty years ago, nuclear power appeared to be a

viable replacement for fossil power, but today it represents less than 15% of U.S. generating capacity. However, as a result of low public support during recent decades and a reduction in the rate of expected power demand, no increase in nuclear power generation is expected in the foreseeable future. As current nuclear power plants age, many plants may be retired during the first quarter of the 21st century, although some may have their operation extended through license renewal. As a result, many nuclear plants are likely to be replaced with coal-fired plants unless it is considered feasible to replace them with fuel sources such as natural gas and solar energy.



As the world's population increases, the demands for all resources, particularly fuel for electricity, is expected to increase. To meet the demand for electric power, the world population is expected to rely increasingly on combustion of fossil fuels, primarily coal. The world has about 1500 years of known coal resources at the current use rate. The graph above shows the growth in U.S. and world coal combustion for the 50 years preceding 1988, along with projections beyond the year 2040. Using the concentration of uranium and thorium indicated above, the graph below illustrates the historical release quantities of these elements and the releases that can be expected during the first half of the next century, given the predicted growth trends. Using these data, both U.S. and worldwide fissionable uranium-235 and fertile nuclear material releases from coal combustion can be calculated.



Because existing coal-fired power plants vary in size and electrical output, to calculate the annual coal consumption of these facilities, assume that the typical plant has an electrical output of 1000 megawatts. Existing coal-fired plants of this capacity annually burn about 4 million tons of coal each year. Further, considering that in 1982 about 616 million short tons (2000 pounds per ton) of coal was burned in the United States (from 833 million short tons mined, or 74%), the number of typical coal-fired plants necessary to consume this quantity of coal is 154.

Using these data, the releases of radioactive materials per typical plant can be calculated for any year. For the year 1982, assuming coal contains uranium and thorium concentrations of 1.3 ppm and 3.2 ppm, respectively, each typical plant released 5.2 tons of uranium (containing 74 pounds of uranium-235) and 12.8 tons of thorium that year. Total U.S. releases in 1982 (from 154 typical plants) amounted to 801 tons of uranium (containing 11,371 pounds of uranium-235) and 1971 tons of thorium. These figures account for only 74% of releases from combustion of coal from all sources. Releases in 1982 from worldwide combustion of 2800 million tons of coal totaled 3640 tons of uranium (containing 51,700 pounds of uranium-235) and 8960 tons of thorium.

Based on the predicted combustion of 2516 million tons of coal in the United States and 12,580 million tons worldwide during the year 2040, cumulative releases for the 100 years of coal combustion following 1937 are predicted to be:

U.S. release (from combustion of 111,716 million tons):

Uranium: 145,230 tons (containing 1031 tons of uranium-235)

Thorium: 357,491 tons

Worldwide release (from combustion of 637,409 million tons):

Uranium: 828,632 tons (containing 5883 tons of uranium-235)

Thorium: 2,039,709 tons

Radioactivity from Coal Combustion

The main sources of radiation released from coal combustion include not only uranium and thorium but also daughter products produced by the decay of these isotopes, such as radium, radon, polonium, bismuth, and lead. Although not a decay product, naturally occurring radioactive potassium-40 is also a significant contributor.

*The population effective dose
equivalent from coal plants is 100
times that from nuclear plants*

According to the National Council on Radiation Protection and Measurements (NCRP), the average radioactivity per short ton of coal is 17,100 millicuries/4,000,000 tons, or 0.00427 millicuries/ton. This figure can be used to calculate the average expected radioactivity release from coal combustion. For 1982 the total release of radioactivity from 154 typical coal plants in the United States was, therefore, 2,630,230 millicuries.

Thus, by combining U.S. coal combustion from 1937 (440 million tons) through 1987 (661 million tons) with an estimated total in the year 2040 (2516 million tons), the total expected U.S. radioactivity release to the environment by 2040 can be determined. That total comes from the expected combustion of 111,716 million tons of coal with the release of 477,027,320 millicuries in the United States. Global releases of radioactivity from the predicted combustion of 637,409 million tons of coal would be 2,721,736,430 millicuries.

For comparison, according to NCRP Reports No. 92 and No. 95, population exposure from operation of 1000-MWe nuclear and coal-fired power plants amounts to 490 person-rem/year for coal plants and 4.8 person-rem/year for nuclear plants. Thus, the population effective dose equivalent from coal plants is 100 times that from nuclear plants. For the complete nuclear fuel cycle, from mining to reactor operation to waste disposal, the radiation dose is cited as 136 person-rem/year; the equivalent dose for coal use, from mining to power plant operation to waste disposal, is not listed in this report and is probably unknown.

During combustion, the volume of coal is reduced by over 85%, which increases the concentration of the metals originally in the coal. Although significant quantities of ash are retained by precipitators, heavy metals such as uranium tend to concentrate on the tiny glass spheres that make up the bulk of fly ash. This uranium is released to the atmosphere with the escaping fly ash, at about 1.0% of the original amount, according to NCRP data. The retained ash is enriched in uranium several times over the original uranium concentration in the coal because the uranium, and thorium, content is not decreased as the volume of coal is reduced.

All studies of potential health hazards associated with the release of radioactive elements from coal combustion conclude that the perturbation of natural background dose levels is almost negligible. However, because the half-lives of radioactive potassium-40, uranium, and thorium are practically infinite in terms of human lifetimes, the accumulation of these species in the biosphere is directly proportional to the length of time that a quantity of coal is burned.

Although trace quantities of radioactive heavy metals are not nearly as likely to produce adverse health effects as the vast array of chemical by-products from coal combustion, the accumulated quantities of

these isotopes over 150 or 250 years could pose a significant future ecological burden and potentially produce adverse health effects, especially if they are locally accumulated. Because coal is predicted to be the primary energy source for electric power production in the foreseeable future, the potential impact of long-term accumulation of by-products in the biosphere should be considered.

*The energy content of nuclear fuel
released in coal combustion is greater
than that of the coal consumed*

Energy Content: Coal vs Nuclear

An average value for the thermal energy of coal is approximately 6150 kilowatt-hours(kWh)/ton. Thus, the expected cumulative thermal energy release from U.S. coal combustion over this period totals about 6.87×10^{14} kilowatt-hours. The thermal energy released in nuclear fission produces about 2×10^9 kWh/ton. Consequently, the thermal energy from fission of uranium-235 released in coal combustion amounts to 2.1×10^{12} kWh. If uranium-238 is bred to plutonium-239, using these data and assuming a "use factor" of 10%, the thermal energy from fission of this isotope alone constitutes about 2.9×10^{14} kWh, or about half the anticipated energy of all the utility coal burned in this country through the year 2040. If the thorium-232 is bred to uranium-233 and fissioned with a similar "use factor", the thermal energy capacity of this isotope is approximately 7.2×10^{14} kWh, or 105% of the thermal energy released from U.S. coal combustion for a century. Assuming 10% usage, the total of the thermal energy capacities from each of these three fissionable isotopes is about 10.1×10^{14} kWh, 1.5 times more than the total from coal. World combustion of coal has the same ratio, similarly indicating that coal combustion wastes more energy than it produces.



Views of the Tennessee Valley Authority's Bull Run and Kingston Steam Plants. These coal-fired facilities generate electricity for Oak Ridge and the surrounding area.

Consequently, the energy content of nuclear fuel released in coal combustion is more than that of the coal consumed! Clearly, coal-fired power plants are not only generating electricity but are also releasing nuclear fuels whose commercial value for electricity production by nuclear power plants is over \$7 trillion, more than the U.S. national debt. This figure is based on current nuclear utility fuel costs of 7 mils per kWh, which is about half the cost for coal. Consequently, significant quantities of nuclear materials are being treated as coal waste, which might become the cleanup nightmare of the future, and their value is hardly recognized at all.

How does the amount of nuclear material released by coal combustion compare to the amount consumed as fuel by the U.S. nuclear power industry? According to 1982 figures, 111 American nuclear plants consumed about 540 tons of nuclear fuel, generating almost 1.1×10^{12} kWh of electricity. During the same year, about 801 tons of uranium alone were released from American coal-fired plants. Add 1971 tons of thorium, and the release of nuclear components from coal combustion far exceeds the entire U.S. consumption of nuclear fuels. The same conclusion applies for worldwide nuclear fuel and coal

combustion.

Another unrecognized problem is the gradual production of plutonium-239 through the exposure of uranium-238 in coal waste to neutrons from the air. These neutrons are produced primarily by bombardment of oxygen and nitrogen nuclei in the atmosphere by cosmic rays and from spontaneous fission of natural isotopes in soil. Because plutonium-239 is reportedly toxic in minute quantities, this process, however slow, is potentially worrisome. The radiotoxicity of plutonium-239 is 3.4×10^{11} times that of uranium-238. Consequently, for 801 tons of uranium released in 1982, only 2.2 milligrams of plutonium-239 bred by natural processes, if those processes exist, is necessary to double the radiotoxicity estimated to be released into the biosphere that year. Only 0.075 times that amount in plutonium-240 doubles the radiotoxicity. Natural processes to produce both plutonium-239 and plutonium-240 appear to exist.

Conclusions

For the 100 years following 1937, U.S. and world use of coal as a heat source for electric power generation will result in the distribution of a variety of radioactive elements into the environment. This prospect raises several questions about the risks and benefits of coal combustion, the leading source of electricity production.

First, the potential health effects of released naturally occurring radioactive elements are a long-term issue that has not been fully addressed. Even with improved efficiency in retaining stack emissions, the removal of coal from its shielding overburden in the earth and subsequent combustion releases large quantities of radioactive materials to the surface of the earth. The emissions by coal-fired power plants of greenhouse gases, a vast array of chemical by-products, and naturally occurring radioactive elements make coal much less desirable as an energy source than is generally accepted.

Second, coal ash is rich in minerals, including large quantities of aluminum and iron. These and other products of commercial value have not been exploited.

Third, large quantities of uranium and thorium and other radioactive species in coal ash are not being treated as radioactive waste. These products emit low-level radiation, but because of regulatory differences, coal-fired power plants are allowed to release quantities of radioactive material that would provoke enormous public outcry if such amounts were released from nuclear facilities. Nuclear waste products from coal combustion are allowed to be dispersed throughout the biosphere in an unregulated manner. Collected nuclear wastes that accumulate on electric utility sites are not protected from weathering, thus exposing people to increasing quantities of radioactive isotopes through air and water movement and the food chain.

Fourth, by collecting the uranium residue from coal combustion, significant quantities of fissionable material can be accumulated. In a few year's time, the recovery of the uranium-235 released by coal combustion from a typical utility anywhere in the world could provide the equivalent of several World War II-type uranium-fueled weapons. Consequently, fissionable nuclear fuel is available to any country that either buys coal from outside sources or has its own reserves. The material is potentially employable as weapon fuel by any organization so inclined. Although technically complex, purification and enrichment technologies can provide high-purity, weapons-grade uranium-235. Fortunately, even though the technology is well known, the enrichment of uranium is an expensive and time-consuming process.

Because electric utilities are not high-profile facilities, collection and processing of coal ash for recovery

of minerals, including uranium for weapons or reactor fuel, can proceed without attracting outside attention, concern, or intervention. Any country with coal-fired plants could collect combustion by-products and amass sufficient nuclear weapons material to build up a very powerful arsenal, if it has or develops the technology to do so. Of far greater potential are the much larger quantities of thorium-232 and uranium-238 from coal combustion that can be used to breed fissionable isotopes. Chemical separation and purification of uranium-233 from thorium and plutonium-239 from uranium require far less effort than enrichment of isotopes. Only small fractions of these fertile elements in coal combustion residue are needed for clandestine breeding of fissionable fuels and weapons material by those nations that have nuclear reactor technology and the inclination to carry out this difficult task.

Fifth, the fact that large quantities of uranium and thorium are released from coal-fired plants without restriction raises a paradoxical question. Considering that the U.S. nuclear power industry has been required to invest in expensive measures to greatly reduce releases of radioactivity from nuclear fuel and fission products to the environment, should coal-fired power plants be allowed to do so without constraints?

If increased regulation of nuclear power plants is demanded, then we can expect a significant redirection of national policy in regulation of radioactive emissions from coal combustion

This question has significant economic repercussions. Today nuclear power plants are not as economical to construct as coal-fired plants, largely because of the high cost of complying with regulations to restrict emissions of radioactivity. If coal-fired power plants were regulated in a similar manner, the added cost of handling nuclear waste from coal combustion would be significant and would, perhaps, make it difficult for coal-burning plants to compete economically with nuclear power.

Because of increasing public concern about nuclear power and radioactivity in the environment, reduction of releases of nuclear materials from all sources has become a national priority known as "as low as reasonably achievable" (ALARA). If increased regulation of nuclear power plants is demanded, can we expect a significant redirection of national policy so that radioactive emissions from coal combustion are also regulated?

Although adverse health effects from increased natural background radioactivity may seem unlikely for the near term, long-term accumulation of radioactive materials from continued worldwide combustion of coal could pose serious health hazards. Because coal combustion is projected to increase throughout the world during the next century, the increasing accumulation of coal combustion by-products, including radioactive components, should be discussed in the formulation of energy policy and plans for future energy use.

One potential solution is improved technology for trapping the exhaust (gaseous emissions up the stack) from coal combustion. If and when such technology is developed, electric utilities may then be able both to recover useful elements, such as nuclear fuels, iron, and aluminum, and to trap greenhouse gas emissions. Encouraging utilities to enter mineral markets that have been previously unavailable may or may not be desirable, but doing so appears to have the potential of expanding their economic base, thus offsetting some portion of their operating costs, which ultimately could reduce consumer costs for electricity.

Both the benefits and hazards of coal combustion are more far-reaching than are generally recognized. Technologies exist to remove, store, and generate energy from the radioactive isotopes released to the environment by coal combustion. When considering the nuclear consequences of coal combustion,

policymakers should look at the data and recognize that the amount of uranium-235 alone dispersed by coal combustion is the equivalent of dozens of nuclear reactor fuel loadings. They should also recognize that the nuclear fuel potential of the fertile isotopes of thorium-232 and uranium-238, which can be converted in reactors to fissionable elements by breeding, yields a virtually unlimited source of nuclear energy that is frequently overlooked as a natural resource.


*The amount of uranium-235 alone dispersed
by coal combustion is the equivalent of
dozens of nuclear reactor fuel loadings*

In short, naturally occurring radioactive species released by coal combustion are accumulating in the environment along with minerals such as mercury, arsenic, silicon, calcium, chlorine, and lead, sodium, as well as metals such as aluminum, iron, lead, magnesium, titanium, boron, chromium, and others that are continually dispersed in millions of tons of coal combustion by-products. The potential benefits and threats of these released materials will someday be of such significance that they should not now be ignored.--Alex Gabbard of the Metals and Ceramics Division

References and Suggested Reading

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Where to?

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FLKE-009

ATTACHMENT D

SECTION 40 CFR 302.6 (c)(3)

Categories of releases exempt from notification requirements:

Coal & Coal ash

Environmental Protection Agency

§ 302.6

In table 302.4 and appendix B to the table are in conflict, the lowest RQ shall apply.

(b) *Unlisted hazardous substances.* Unlisted hazardous substances designated by 40 CFR 302.4(b) have the reportable quantity of 100 pounds, except for those unlisted hazardous wastes which exhibit extraction procedure (EP) toxicity identified in 40 CFR 261.24. Unlisted hazardous wastes which exhibit EP toxicity have the reportable quantities listed in table 302.4 for the contaminant on which the characteristic of EP toxicity is based. The reportable quantity applies to the waste itself, not merely to the toxic contaminant. If an unlisted hazardous waste exhibits EP toxicity on the basis of more than one contaminant, the reportable quantity for that waste shall be the lowest of the reportable quantities listed in table 302.4 for those contaminants. If an unlisted hazardous waste exhibits the characteristic of EP toxicity and one or more of the other characteristics referenced in 40 CFR 302.4(b), the reportable quantity for that waste shall be the lowest of the applicable reportable quantities.

[51 FR 34547, Sept. 29, 1987, as amended at 54 FR 22538, May 24, 1989]

§ 302.6 Notification requirements.

(a) Any person in charge of a vessel or an offshore or an onshore facility shall, as soon as he has knowledge of any release (other than a federally permitted release or application of a pesticide) of a hazardous substance from such vessel or facility in a quantity equal to or exceeding the reportable quantity determined by this part, in any 24-hour period, immediately notify the National Response Center ((800) 424-8802; in Washington, DC (202) 426-2675).

(b) Releases of mixtures or solutions (including hazardous waste streams) of

(1) Hazardous substances, except for radionuclides, are subject to the following notification requirements:

(i) If the quantity of all of the hazardous constituent(s) of the mixture or solution is known, notification is required where an RQ or more of any hazardous constituent is released.

(ii) If the quantity of one or more of the hazardous constituent(s) of the

mixture or solution is unknown, notification is required where the total amount of the mixture or solution released equals or exceeds the RQ for the hazardous constituent with the lowest RQ; or

(iii) For waste streams K169, K170, K171, and K172, knowledge of the quantity of all of the hazardous constituent(s) may be assumed, based on the following maximum observed constituent concentrations identified by EPA:

Waste	Constituent	Max ppm
K169	Benzene	220.0
K170	Benzene	1.2
	Benzo (a) pyrene	230.0
	Dibenz (a,h) anthracene	49.0
	Benzo (a) anthracene	390.0
	Benzo (b) fluoranthene	110.0
	Benzo (k) fluoranthene	110.0
	3-Methylcholanthrene	27.0
	7,12-Dimethylbenz (a) anthracene ..	1,200.0
K171	Benzene	500.0
	Arsenic	1,600.0
K172	Benzene	100.0
	Arsenic	730.0

(2) Radionuclides are subject to this section's notification requirements only in the following circumstances:

(i) If the identity and quantity (in curies) of each radionuclide in a released mixture or solution is known, the ratio between the quantity released (in curies) and the RQ for the radionuclide must be determined for each radionuclide. The only such releases subject to this section's notification requirements are those in which the sum of the ratios for the radionuclides in the mixture or solution released is equal to or greater than one.

(ii) If the identity of each radionuclide in a released mixture or solution is known but the quantity released (in curies) of one or more of the radionuclides is unknown, the only such releases subject to this section's notification requirements are those in which the total quantity (in curies) of the mixture or solution released is equal to or greater than the lowest RQ of any individual radionuclide in the mixture or solution.

(iii) If the identity of one or more radionuclides in a released mixture or solution is unknown (or if the identity of a radionuclide released by itself is

§ 302.7

40 CFR Ch. I (7-1-00 Edition)

unknown), the only such releases subject to this section's notification requirements are those in which the total quantity (in curies) released is equal to or greater than either one curie or the lowest RQ of any known individual radionuclide in the mixture or solution, whichever is lower.

(c) The following categories of releases are exempt from the notification requirements of this section:

(1) Releases of those radionuclides that occur naturally in the soil from land holdings such as parks, golf courses, or other large tracts of land.

(2) Releases of naturally occurring radionuclides from land disturbance activities, including farming, construction, and land disturbance incidental to extraction during mining activities, except that which occurs at uranium, phosphate, tin, zircon, hafnium, vanadium, monazite, and rare earth mines. Land disturbance incidental to extraction includes: land clearing; overburden removal and stockpiling; excavating, handling, transporting, and storing ores and other raw (not beneficiated or processed) materials; and replacing in mined-out areas coal ash, earthen materials from farming or construction, or overburden or other raw materials generated from the exempted mining activities.

(3) Releases of radionuclides from the dumping and transportation of coal and coal ash (including fly ash, bottom ash, and boiler slags), including the dumping and land spreading operations that occur during coal ash uses.

(4) Releases of radionuclides from piles of coal and coal ash, including fly ash, bottom ash, and boiler slags.

(d) Except for releases of radionuclides, notification of the release of an RQ of solid particles of antimony, arsenic, beryllium, cadmium, chromium, copper, lead, nickel, selenium, silver, thallium, or zinc is not required if the mean diameter of the particles released is larger than 100 micrometers (0.004 inches).

[50 FR 13474, Apr. 4, 1985, as amended at 54 FR 22538, May 24, 1989; 54 FR 33481, Aug. 14, 1989; 63 FR 13475, Mar. 19, 1998; 63 FR 42189, Aug. 6, 1998; 64 FR 13114, Mar. 17, 1999]

§ 302.7 Penalties.

(a) Any person—

(1) In charge of a vessel from which a hazardous substance is released, other than a federally permitted release, into or upon the navigable waters of the United States, adjoining shorelines, or into or upon the waters of the contiguous zone.

(2) In charge of a vessel from which a hazardous substance is released, other than a federally permitted release, which may affect natural resources belonging to, appertaining to, or under the exclusive management authority of the United States (including resources under the Fishery Conservation and Management Act of 1976), and who is otherwise subject to the jurisdiction of the United States at the time of the release, or

(3) In charge of a facility from which a hazardous substance is released, other than a federally permitted release, in a quantity equal to or greater than that reportable quantity determined under this part who fails to notify immediately the National Response Center as soon as he has knowledge of such release shall be subject to all of the sanctions, including criminal penalties, set forth in section 103 of the Act with respect to such failure to notify.

(b) Notification received pursuant to this section or information obtained by the exploitation of such notification shall not be used against any such person in any criminal case, except a prosecution for perjury or for giving a false statement.

(c) This section shall not apply to the application of a pesticide product registered under the Federal Insecticide, Fungicide, and Rodenticide Act or to the handling and storage of such a pesticide product by an agricultural producer.

§ 302.8 Continuous releases.

(a) Except as provided in paragraph (c) of this section, no notification is required for any release of a hazardous substance that is, pursuant to the definitions in paragraph (b) of this section, continuous and stable in quantity and rate.

(b) *Definitions.* The following definitions apply to notification of continuous releases:

FLKE-009

ATTACHMENT E

RADIOCHEMICAL RESULTS FOR DUSABLE PARK SAMPLES

EPA National Air & Radiation Environmental Laboratory

December 23, 2002

January 7, 2003

Bernie,

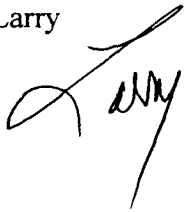
JAN 13 2003

Some notes on this data.

- Your Marinelli's did not fit on NAREL's spectrometer, slightly different core diameter on the beakers. NAREL did count them nevertheless but they do not consider this valid data. See Table 1.
- NAREL repackaged the soil in their own Marinellis and counted them. See data package and Table 2.
- When the beakers were returned to me, I sifted the soil with our usual quarter inch screen, weighed the two fractions and calculated what the concentrations would have been if we had sifted the samples per our usual protocol in Streeterville. See Tables 3 and 4

Any questions, feel free to call.

Larry

A handwritten signature in black ink, appearing to be 'Larry', written over a horizontal line.



UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RADIATION AND INDOOR AIR
National Air and Radiation Environmental Laboratory
540 South Morris Avenue, Montgomery, AL 36115-2601
(334) 270-3400

December 23, 2002

MEMORANDUM

SUBJECT: Radiochemical Results for
DuSable Park Samples

FROM: John Griggs, Chief *John Griggs*
Monitoring and Analytical Services Branch

TO: Larry Jensen, Health Physicist
Region 5

Attached is a data package for gamma analysis of samples collected from the DuSable Park Site in Chicago, IL. The samples constitute NAREL batch numbers 0200060.

Radiochemical analyses usually require the subtraction of an instrument background measurement from a gross sample measurement. Both values are positive, but when the sample activity is low, random variations in the two measurements can cause the gross value to be less than the background, resulting in a measured activity less than zero. Although negative activities have no physical significance, they do have statistical significance, as for example in the evaluation of trends or the comparison of two groups of samples.

For all analyses except gamma spectroscopy, it is the policy of NAREL to report results as generated, whether positive, negative, or zero, together with the 2-sigma measurement uncertainty and a sample-specific estimate of the minimum detectable concentration (MDC). The activity, uncertainty, and MDC are given in the same units. The activity and 2-sigma uncertainty for a radionuclide measured by gamma spectroscopy are reported only if the nuclide is detected; so, the results of gamma analyses are never zero or negative. Nuclides that are not detected do not appear in the report, with the exception of Ba-140, Co-60, Cs-137, I-131, K-40, Ra-226, and Ra-228. If one of these seven nuclides is undetected, NAREL reports it as "Not Detected," or "ND," and provides a sample-specific estimate of the MDC.

Specific information concerning all aspects of the radiological analysis of the samples is contained in the batch case narrative of the data package. If you have any questions concerning the analytical results, please contact me at (334)270-3450.

Attachments

cc: Jack Barnette, Region 5, w/o attachments
Steve Ostrodka, SF, Region 5, w/o attachments
Mary Clark, (6601J), w/o attachments
Ed Sensintaffar, NAREL

**U.S. ENVIRONMENTAL PROTECTION AGENCY
NATIONAL AIR AND RADIATION ENVIRONMENTAL LABORATORY
GAMMA ANALYSES**

REPORT OF SAMPLE DELIVERY GROUP #0200060

Project: DUSABLE PARK
Analysis Procedure: Gamma Spectrometry
Date Reported: 12/05/2002

SAMPLES

NAREL Sample #	Client Sample ID	Type	Matrix	Date Collected	Date Received
A2.05326G	B-1	SAM	SOIL	10/07/2002	11/12/2002
A2.05327H	B-3	SAM	SOIL	10/07/2002	11/12/2002
A2.05328J	B-2	SAM	SOIL	10/07/2002	11/12/2002
A2.05329K	C	SAM	SOIL	10/07/2002	11/12/2002
A2.05330C	A	SAM	SOIL	10/07/2002	11/12/2002

EXCEPTIONS

1. Packaging and Shipping - No problems were observed.
2. Documentation - No problems were observed.
3. Sample Preparation - No problems were encountered.
4. Analysis - No problems were encountered.
5. Holding Times - All holding times were met.

QUALITY CONTROL

1. QC samples - All QC analysis results met NAREL acceptance criteria except the ^{234}Th results which can be over or underestimated by gamma analysis. Please see the general information section of this data package for further explanation.
2. Instruments - Response and background checks for all instruments used in these analyses met NAREL acceptance criteria.

CERTIFICATION

I certify that this data report complies with the terms and conditions of the Quality Assurance Project Plan, except as noted above. Release of the data contained in this report has been authorized by the Chief of the Monitoring and Analytical Services Branch and the NAREL Quality Assurance Coordinator, or their designees, as verified by the following signatures.

Mary F. Wisdom 12/18/02
Mary F. Wisdom Date
Quality Assurance Coordinator

John Griggs 12/11/02
John Griggs, Ph.D. Date
Chief, Monitoring and Analytical Services Branch

GENERAL INFORMATION

SAMPLE TYPES

BLD	Blind sample
FBK	Field blank
SAM	Normal sample

ANALYSIS QC TYPES

ANA	Normal analysis
DUP	Laboratory duplicate
LCS	Laboratory control sample (blank spike)
MS	Matrix spike
MSD	Matrix spike duplicate
RBK	Reagent blank

QUALITY INDICATORS

RPD	Relative Percent Difference
%R	Percent Recovery
Z	Number of standard deviations by which a QC measurement differs from the expected value

EVALUATION OF QC ANALYSES

A reagent blank result is considered unacceptable if it is more than 3 standard deviations below zero or more than 3 standard deviations above a predetermined upper control limit. For some analyses NAREL has set the upper control limit at zero. For others the control limit is a small positive number.

NAREL evaluates the results of duplicate and spike analyses using "Z scores." A Z score is the number of standard deviations by which the QC result differs from its ideal value. The score is considered acceptable if its absolute value is not greater than 3.

The Z score for a spiked sample is computed by dividing the difference between the measured value and the target value by the combined standard uncertainty of the difference.

The Z score for a duplicate analysis is computed by dividing the difference between the two measured values by the combined standard uncertainty of the difference. When the precision of paired MS/MSD analyses is evaluated, the native sample activity is subtracted from each measured value and the net concentrations are then converted to total activities before the Z score is computed.

Each standard uncertainty used to compute a Z score includes an additional fixed term to represent sources of measurement error other than counting error. This additional term is not used in the evaluation of reagent blanks.

NAREL reports the "relative percent difference," or RPD, between duplicate results and the "percent recovery," or %R, for spiked analyses, but does not use these values for evaluation.

GENERAL INFORMATION (CONTINUED)

GAMMA ANALYSIS

The reporting format lists the gamma emitters in alphabetical order. The activity and 2-sigma uncertainty for radionuclides measured by gamma spectroscopy are reported only if the nuclide is detected. Nuclides that are not detected do not appear in the report, with the exception of Ba-140, Co-60, Cs-137, I-131, K-40, Ra-226 and Ra-228. If one of these seven nuclides is undetected, NAREL reports it as "Not Detected" or "ND", and provides a sample-specific estimate of the MDC.

Due to potential spectral interferences and other possible problems associated with the determination of the activity of certain radionuclides, the activities for Th-234, Pa-234m, Ra-226, Th-231, and U-235 are subject to greater possible uncertainty than other commonly reported radionuclides. It should be noted that this potential uncertainty is not included in the two-sigma counting uncertainty which is reported with each activity. Although in this report we do provide the calculated activities for these radionuclides, we recommend that the results be used only as a qualitative means of indicating the presence of these radionuclides and not as a quantitative measure of their concentration. The results for these nuclides are not used in the evaluation of quality control samples. Furthermore, because of mutual interference between Ra-226 and U-235, NAREL's gamma analysis software tends to overestimate the amounts of these nuclides whenever both are present in a sample. Lower estimates for Ra-226 activities can be obtained from the reported activities of its decay products, Pb-214 and Bi-214, which are likely to be somewhat less than the Ra-226 activity because of the potential escape of radon gas.

NAREL's gamma spectroscopy software corrects activities and MDCs for decay between collection and analysis, but only up to a limit of ten half-lives. So, if the decay time for a sample is more than ten half-lives of a radionuclide, that nuclide will almost always be undetected and the reported MDC will be meaningless. This is usually a problem only for short-lived radionuclides, such as I-131 and Ba-140, when there is a long delay between collection and analysis.

**U.S. ENVIRONMENTAL PROTECTION AGENCY
NATIONAL AIR AND RADIATION ENVIRONMENTAL LABORATORY
GAMMA ANALYSES
SDG #0200060**

ANALYSIS SUMMARY

Analysis Procedure: NAREL GAM-01
Title: Gamma Spectrometry

NAREL Sample #	QC Type	Preparation Procedure	Date Completed	Prep Batch #	QC Batch #
A2.05326G		N/A	11/15/2002	0007275H	0002674N
A2.05327H		N/A	11/15/2002	0007275H	0002674N
A2.05328J		N/A	11/15/2002	0007275H	0002674N
A2.05329K		N/A	11/15/2002	0007275H	0002674N
A2.05330C		N/A	11/15/2002	0007275H	0002674N
A2.05330C	DUP	N/A	11/19/2002	0007275H	0002674N

* Samples marked with an asterisk are not in this sample delivery group but were analyzed with it for QC purposes.

**U.S. ENVIRONMENTAL PROTECTION AGENCY
NATIONAL AIR AND RADIATION ENVIRONMENTAL LABORATORY
GAMMA ANALYSES
SDG #0200060**

SAMPLE ANALYSIS REPORT

Sample #:	A2.05326G	QC batch #:	0002674N
Matrix:	SOIL	Prep batch #:	0007275H
Sample type:	SAM	Prep procedure:	N/A
Amount analyzed:	2.000e+03 GWET	Analysis procedure:	NAREL GAM-01
Dry/wet weight:	N/A	Analyst:	N/A
Ash/dry weight:	N/A	QC type:	ANA

Comment: DUSABLE PARK SITE

COUNTING INFORMATION

Date and time	Duration (min)	Detector ID	Operator
11/14/2002 15:02	1000.0	GE01	KNG

ANALYTICAL RESULTS

Analyte	Activity	$\pm 2\sigma$ Uncertainty	MDC	Unit	Date
Ba140	ND		3.5e-01	PCI/GWET	10/07/2002
Bi212	4.79e-01 \downarrow	1.1e-01		PCI/GWET	10/07/2002
Bi214 *	6.45e-01 \uparrow	4.0e-02		PCI/GWET	10/07/2002
Co60	ND		2.5e-02	PCI/GWET	10/07/2002
Cs137	ND		1.6e-02	PCI/GWET	10/07/2002
I131	ND		2.6e-01	PCI/GWET	10/07/2002
K40	7.50e+00 \uparrow	4.6e-01		PCI/GWET	10/07/2002
Pb212	6.00e-01 \downarrow	3.6e-02		PCI/GWET	10/07/2002
Pb214 *	7.20e-01 \uparrow	4.3e-02		PCI/GWET	10/07/2002
Ra224	6.02e-01 \uparrow	1.4e-01		PCI/GWET	10/07/2002
Ra226 *	1.57e+00 \uparrow	1.4e-01		PCI/GWET	10/07/2002
Ra228	5.15e-01 \downarrow	3.6e-02		PCI/GWET	10/07/2002
Th234 *	9.60e-01 \downarrow	8.3e-02		PCI/GWET	10/07/2002
Tl208	1.74e-01 \downarrow	1.3e-02		PCI/GWET	10/07/2002
U235 *	9.34e-02 \sim	8.5e-03		PCI/GWET	10/07/2002

* An asterisk indicates a result whose value may be significantly over or underestimated.

**U.S. ENVIRONMENTAL PROTECTION AGENCY
NATIONAL AIR AND RADIATION ENVIRONMENTAL LABORATORY
GAMMA ANALYSES
SDG #0200060**

SAMPLE ANALYSIS REPORT

Sample #:	A2.05327H	QC batch #:	0002674N
Matrix:	SOIL	Prep batch #:	0007275H
Sample type:	SAM	Prep procedure:	N/A
Amount analyzed:	1.810e+03 GWET	Analysis procedure:	NAREL GAM-01
Dry/wet weight:	N/A	Analyst:	N/A
Ash/dry weight:	N/A	QC type:	ANA

Comment: DUSABLE PARK SITE

COUNTING INFORMATION

Date and time	Duration (min)	Detector ID	Operator
11/14/2002 15:02	1000.0	GE02	KNG

ANALYTICAL RESULTS

Analyte	Activity	$\pm 2\sigma$ Uncertainty	MDC	Unit	Date
Ba140	ND		4.7e-01	PCI/GWET	10/07/2002
Bi212	3.12e+00 +	2.4e-01		PCI/GWET	10/07/2002
Bi214 *	7.20e-01 +	4.6e-02		PCI/GWET	10/07/2002
Co60	ND		2.2e-02	PCI/GWET	10/07/2002
Cs137	ND		2.1e-02	PCI/GWET	10/07/2002
I131	ND		4.0e-01	PCI/GWET	10/07/2002
K40	9.46e+00 +	5.8e-01		PCI/GWET	10/07/2002
Pb212	3.21e+00 +	1.8e-01		PCI/GWET	10/07/2002
Pb214 *	7.44e-01 +	4.7e-02		PCI/GWET	10/07/2002
Ra224	2.87e+00 +	2.8e-01		PCI/GWET	10/07/2002
Ra226 *	1.70e+00 +	2.3e-01		PCI/GWET	10/07/2002
Ra228	2.97e+00 +	1.7e-01		PCI/GWET	10/07/2002
Th234 *	7.34e-01 +	2.2e-01		PCI/GWET	10/07/2002
Tl208	1.10e+00 +	6.5e-02		PCI/GWET	10/07/2002

* An asterisk indicates a result whose value may be significantly over or underestimated.

**U.S. ENVIRONMENTAL PROTECTION AGENCY
NATIONAL AIR AND RADIATION ENVIRONMENTAL LABORATORY
GAMMA ANALYSES
SDG #0200060**

SAMPLE ANALYSIS REPORT

Sample #:	A2.05328J	QC batch #:	0002674N
Matrix:	SOIL	Prep batch #:	0007275H
Sample type:	SAM	Prep procedure:	N/A
Amount analyzed:	1.550e+03 GWET	Analysis procedure:	NAREL GAM-01
Dry/wet weight:	N/A	Analyst:	N/A
Ash/dry weight:	N/A	QC type:	ANA

Comment: DUSABLE PARK SITE

COUNTING INFORMATION

Date and time	Duration (min)	Detector ID	Operator
11/14/2002 15:02	1000.0	GE03	KNG

ANALYTICAL RESULTS

Analyte	Activity	$\pm 2\sigma$ Uncertainty	MDC	Unit	Date
Ba140	ND		2.7e-01	PCI/GWET	10/07/2002
Bi212	3.87e+00 ↓	2.4e-01		PCI/GWET	10/07/2002
Bi214 *	6.92e-01 ↑	4.1e-02		PCI/GWET	10/07/2002
Co60	ND		1.1e-02	PCI/GWET	10/07/2002
Cs137	ND		1.1e-02	PCI/GWET	10/07/2002
I131	ND		2.5e-01	PCI/GWET	10/07/2002
K40	6.62e+00 ↓	3.9e-01		PCI/GWET	10/07/2002
Pa234m *	6.26e-01 ↓	4.0e-01		PCI/GWET	10/07/2002
Pb212	3.99e+00 ↓	2.3e-01		PCI/GWET	10/07/2002
Pb214 *	7.21e-01 ↑	4.3e-02		PCI/GWET	10/07/2002
Ra224	4.51e+00 ↑	3.1e-01		PCI/GWET	10/07/2002
Ra226 *	1.65e+00 ↑	1.9e-01		PCI/GWET	10/07/2002
Ra228	3.93e+00 ↑	2.2e-01		PCI/GWET	10/07/2002
Rn220	6.86e+00 ↓	5.0e+00		PCI/GWET	10/07/2002
Tl208	1.33e+00 ↑	7.6e-02		PCI/GWET	10/07/2002

* An asterisk indicates a result whose value may be significantly over or underestimated.

**U.S. ENVIRONMENTAL PROTECTION AGENCY
NATIONAL AIR AND RADIATION ENVIRONMENTAL LABORATORY
GAMMA ANALYSES
SDG #0200060**

SAMPLE ANALYSIS REPORT

Sample #:	A2.05329K	QC batch #:	0002674N
Matrix:	SOIL	Prep batch #:	0007275H
Sample type:	SAM	Prep procedure:	N/A
Amount analyzed:	1.570e+03 GWET	Analysis procedure:	NAREL GAM-01
Dry/wet weight:	N/A	Analyst:	N/A
Ash/dry weight:	N/A	QC type:	ANA

Comment: DUSABLE PARK SITE

COUNTING INFORMATION

Date and time	Duration (min)	Detector ID	Operator
11/14/2002 15:03	1000.0	GE05	KNG

ANALYTICAL RESULTS

Analyte	Activity	$\pm 2\sigma$ Uncertainty	MDC	Unit	Date
Ba140	ND		5.5e-01	PCI/GWET	10/07/2002
Bi212	6.74e+00 \uparrow	4.2e-01		PCI/GWET	10/07/2002
Bi214 *	1.72e+00 \uparrow	1.0e-01		PCI/GWET	10/07/2002
Co60	ND		1.8e-02	PCI/GWET	10/07/2002
Cs137	ND		2.1e-02	PCI/GWET	10/07/2002
I131	ND		4.5e-01	PCI/GWET	10/07/2002
K40	6.50e+00 \uparrow	3.9e-01		PCI/GWET	10/07/2002
Pa234m *	1.69e+00 \uparrow	7.9e-01		PCI/GWET	10/07/2002
Pb212	6.83e+00 \uparrow	3.9e-01		PCI/GWET	10/07/2002
Pb214 *	1.80e+00 \uparrow	1.0e-01		PCI/GWET	10/07/2002
Ra224	7.86e+00 \uparrow	5.4e-01		PCI/GWET	10/07/2002
Ra226 *	3.82e+00 \uparrow	3.7e-01		PCI/GWET	10/07/2002
Ra228	6.42e+00 \uparrow	3.7e-01		PCI/GWET	10/07/2002
Rn220	1.34e+01 \uparrow	9.5e+00		PCI/GWET	10/07/2002
Th234 *	1.92e+00 \uparrow	3.0e-01		PCI/GWET	10/07/2002
Tl208	2.34e+00 \uparrow	1.3e-01		PCI/GWET	10/07/2002
U235 *	2.26e-01 \uparrow	2.2e-02		PCI/GWET	10/07/2002

* An asterisk indicates a result whose value may be significantly over or underestimated.

**U.S. ENVIRONMENTAL PROTECTION AGENCY
NATIONAL AIR AND RADIATION ENVIRONMENTAL LABORATORY
GAMMA ANALYSES
SDG #0200060**

SAMPLE ANALYSIS REPORT

Sample #:	A2.05330C	QC batch #:	0002674N
Matrix:	SOIL	Prep batch #:	0007275H
Sample type:	SAM	Prep procedure:	N/A
Amount analyzed:	2.080e+03 GWET	Analysis procedure:	NAREL GAM-01
Dry/wet weight:	N/A	Analyst:	N/A
Ash/dry weight:	N/A	QC type:	ANA

Comment: DUSABLE PARK SITE

COUNTING INFORMATION

Date and time	Duration (min)	Detector ID	Operator
11/14/2002 15:03	1000.0	GE11	KNG

ANALYTICAL RESULTS

Analyte	Activity	$\pm 2\sigma$ Uncertainty	MDC	Unit	Date
Ba140	ND		3.0e-01	PCI/GWET	10/07/2002
Bi212	4.29e+00 +	2.6e-01		PCI/GWET	10/07/2002
Bi214 *	1.19e+00 +	6.9e-02		PCI/GWET	10/07/2002
Co60	ND		9.5e-03	PCI/GWET	10/07/2002
Cs137	2.45e-02 +	6.5e-03		PCI/GWET	10/07/2002
I131	ND		2.7e-01	PCI/GWET	10/07/2002
K40	7.31e+00 f	4.2e-01		PCI/GWET	10/07/2002
Pa234m *	9.25e-01 +	4.3e-01		PCI/GWET	10/07/2002
Pb212	4.25e+00 +	2.4e-01		PCI/GWET	10/07/2002
Pb214 *	1.24e+00 +	7.2e-02		PCI/GWET	10/07/2002
Ra224	4.45e+00 +	3.0e-01		PCI/GWET	10/07/2002
Ra226 *	2.42e+00 +	2.2e-01		PCI/GWET	10/07/2002
Ra228	4.09e+00 +	2.3e-01		PCI/GWET	10/07/2002
Rn220	7.50e+00 +	4.7e+00		PCI/GWET	10/07/2002
Th234 *	5.95e-01 +	1.4e-01		PCI/GWET	10/07/2002
Tl208	1.43e+00 +	8.2e-02		PCI/GWET	10/07/2002
U235 *	1.39e-01 +	1.3e-02		PCI/GWET	10/07/2002

* An asterisk indicates a result whose value may be significantly over or underestimated.

**U.S. ENVIRONMENTAL PROTECTION AGENCY
NATIONAL AIR AND RADIATION ENVIRONMENTAL LABORATORY
GAMMA ANALYSES
SDG #0200060**

SAMPLE ANALYSIS REPORT

Sample #:	A2.05330C	QC batch #:	0002674N
Matrix:	SOIL	Prep batch #:	0007275H
Sample type:	SAM	Prep procedure:	N/A
Amount analyzed:	2.080e+03 GWET	Analysis procedure:	NAREL GAM-01
Dry/wet weight:	N/A	Analyst:	N/A
Ash/dry weight:	N/A	QC type:	DUP

Comment: DUSABLE PARK SITE

COUNTING INFORMATION

Date and time	Duration (min)	Detector ID	Operator
11/18/2002 14:16	1000.0	GE18	KNG

ANALYTICAL RESULTS

Analyte	Activity	$\pm 2\sigma$ Uncertainty	MDC	Unit	Date
Ba140	ND		2.8e-01	PCI/GWET	10/07/2002
Bi212	4.26e+00	2.6e-01		PCI/GWET	10/07/2002
Bi214 *	1.23e+00	7.1e-02		PCI/GWET	10/07/2002
Co60	ND		9.6e-03	PCI/GWET	10/07/2002
Cs137	2.62e-02	5.6e-03		PCI/GWET	10/07/2002
I131	ND		2.7e-01	PCI/GWET	10/07/2002
K40	7.56e+00	4.4e-01		PCI/GWET	10/07/2002
Pa234m *	1.82e+00	4.7e-01		PCI/GWET	10/07/2002
Pb212	4.17e+00	2.4e-01		PCI/GWET	10/07/2002
Pb214 *	1.29e+00	7.4e-02		PCI/GWET	10/07/2002
Ra224	4.38e+00	2.9e-01		PCI/GWET	10/07/2002
Ra226 *	2.53e+00	2.0e-01		PCI/GWET	10/07/2002
Ra228	4.14e+00	2.4e-01		PCI/GWET	10/07/2002
Rn220	6.94e+00	3.9e+00		PCI/GWET	10/07/2002
Th228	5.40e+00	1.5e+00		PCI/GWET	10/07/2002
Th234 *	2.49e+00	1.8e-01		PCI/GWET	10/07/2002
Tl208	1.39e+00	7.9e-02		PCI/GWET	10/07/2002
U235 *	1.52e-01	1.2e-02		PCI/GWET	10/07/2002

* An asterisk indicates a result whose value may be significantly over or underestimated.

**U.S. ENVIRONMENTAL PROTECTION AGENCY
NATIONAL AIR AND RADIATION ENVIRONMENTAL LABORATORY
GAMMA ANALYSES
SDG #0200060**

QC BATCH SUMMARY

QC batch #: 0002674N
Preparation procedure: N/A
Analysis procedure: NAREL GAM-01

NAREL Sample #	QC Type	Yield (%)	$\pm 2\sigma$ Uncertainty (%)	Analyst
A2.05326G		N/A		N/A
A2.05327H		N/A		N/A
A2.05328J		N/A		N/A
A2.05329K		N/A		N/A
A2.05330C		N/A		N/A
A2.05330C	DUP	N/A		N/A

* Samples marked with an asterisk are not in this sample delivery group but were analyzed with it for QC purposes.

**National Air and Radiation Environmental Laboratory
QC Batch Report**

QC Batch #: 0002674N

Analytical Procedure: NAREL GAM-01

LABORATORY DUPLICATES (PCI/GWET)

Sample ID	Nuclide	Original $\pm 2\sigma$	Duplicate $\pm 2\sigma$	RPD	Z
A2.05330C	BA140				
A2.05330C	BI212	4.29e+00 \pm 2.6e-01	4.26e+00 \pm 2.6e-01	0.70	-0.09 OK
A2.05330C	BI214	1.19e+00 \pm 6.9e-02	1.23e+00 \pm 7.1e-02	3.31	0.41 OK
A2.05330C	CO60				
A2.05330C	CS137	2.45e-02 \pm 6.5e-03	2.62e-02 \pm 5.6e-03	6.71	0.37 OK
A2.05330C	I131				
A2.05330C	K40	7.31e+00 \pm 4.2e-01	7.56e+00 \pm 4.4e-01	3.36	0.41 OK
A2.05330C	PA234M	9.25e-01 \pm 4.3e-01	1.82e+00 \pm 4.7e-01	65.21	2.68 OK
A2.05330C	PB212	4.25e+00 \pm 2.4e-01	4.17e+00 \pm 2.4e-01	1.90	-0.23 OK
A2.05330C	PB214	1.24e+00 \pm 7.2e-02	1.29e+00 \pm 7.4e-02	3.95	0.48 OK
A2.05330C	RA224	4.45e+00 \pm 3.0e-01	4.38e+00 \pm 2.9e-01	1.59	-0.19 OK
A2.05330C	RA226	2.42e+00 \pm 2.2e-01	2.53e+00 \pm 2.0e-01	4.44	0.48 OK
A2.05330C	RA228	4.09e+00 \pm 2.3e-01	4.14e+00 \pm 2.4e-01	1.22	0.15 OK
A2.05330C	RN220	7.50e+00 \pm 4.7e+00	6.94e+00 \pm 3.9e+00	7.76	-0.18 OK
A2.05330C	TH234	5.95e-01 \pm 1.4e-01	2.49e+00 \pm 1.8e-01	122.85	11.97 HIGH
A2.05330C	TL208	1.43e+00 \pm 8.2e-02	1.39e+00 \pm 7.9e-02	2.84	-0.35 OK
A2.05330C	U235	1.39e-01 \pm 1.3e-02	1.52e-01 \pm 1.2e-02	8.93	0.96 OK

Analyst:

[Signature]

12-10-02

QA Officer:

[Signature]

12/10/02

OK. Th-234 is "estimated".

Table 1: DuSable Park, Exploration Samples---All stones and debris less than 1 inch diameter retained

Samples analyzed at NAREL in Kerr-McGee marinellis

SAMPLE NUMBER	SITE	THORIUM DECAY SERIES (Gamma Spectrometry) (pCi/g)							URANIUM DECAY SERIES (Gamma Spectrometry) (pCi/g)					OTHER (Gamma Spectrometry) (pCi/g)				TOTAL RADIUM (pCi/g)
		Ra-228	Th-228	Ra-224	Rn-220	Pb-212	Bi-212	Tl-208	Th-234	Pa-234m	Ra-226	Pb-214	Bi-214	K-40	Cs-137	U-235	Th-231	
A2.05330G	A	4.52	3.40	5.23	8.90	4.82	4.52	1.61	1.21	0.890	2.94	1.46	1.34	7.94	0.0272	0.178		5.98
A2.05326G	B-1	0.588		0.290		0.647	0.582	0.205	0.880	0.740	1.71	0.839	0.782	9.0	0.0055	0.102		1.43
A2.05328G	B-2	4.26	3.10	5.40		4.77	4.45	1.53		1.00	1.85	0.885	0.783	6.5				5.15
A2.05327G	B-3	3.12		3.21		3.53	3.25	1.16	1.16	0.840	2.04	0.919	0.865	12.2		0.125		4.04
A2.05329G	C	6.91	8.00	9.02	9.90	7.77	7.06	2.51	2.95	2.52	4.40	2.10	1.88	7.0		0.258		9.01

Table 2: DuSable Park, Exploration Samples---All stones and debris less than 1 inch diameter retained

Samples analyzed at NAREL in NAREL marinellis

SAMPLE NUMBER	SITE	THORIUM DECAY SERIES (Gamma Spectrometry) (pCi/g)							URANIUM DECAY SERIES (Gamma Spectrometry) (pCi/g)					OTHER (Gamma Spectrometry) (pCi/g)				TOTAL RADIUM (pCi/g)
		Ra-228	Th-228	Ra-224	Rn-220	Pb-212	Bi-212	Tl-208	Th-234	Pa-234m	Ra-226	Pb-214	Bi-214	K-40	Cs-137	U-235	Th-231	
A2.05330C	A	4.09		4.45	7.50	4.25	4.29	1.43	0.595	0.925	2.42	1.24	1.19	7.31	0.0245	0.139		5.33
A2.05330C, DUP	A	4.14	5.40	4.38	6.94	4.17	4.26	1.39	2.480	1.820	2.53	1.29	1.23	7.56	0.0262	0.152		5.43
A2.05326G	B-1	0.515		0.602		0.600	0.479	0.174	0.960		1.57	0.720	0.645	7.50		0.0934		1.24
A2.05328J	B-2	3.93		4.51	6.86	3.99	3.87	1.33		0.626	1.65	0.721	0.692	6.62				4.65
A2.05327H	B-3	2.97		2.87		3.21	3.12	1.10	0.734		1.70	0.744	0.720	9.46			1.02	3.71
A2.05329K	C	6.42		7.86	13.4	6.83	6.74	2.34	1.92	1.69	3.82	1.80	1.72	6.50		0.226		8.22

Table 3: DuSable Park, Exploration Samples--Soil and stone/debris masses

Samples measured at Region 5 Central Regional Laboratory

SAMPLE NUMBER	SITE	SOIL	SOIL LESS BAGGIE MASS	DEBRIS	DEBRIS LESS BAGGIE MASS	TOTAL LESS BAGGIE MASSES
		(grams)	(grams)	(grams)	(grams)	(grams)
A2.05330C	A	1402	1392	629	619	2011
A2.05326G	B-1	1438	1428	523	513	1941
A2.05328J	B-2	1126	1116	397	387	1503
A2.05327H	B-3	1510	1500	279	269	1769
A2.05329K	C	1085	1075	449	439	1514

Table 4: DuSable Park, Exploration Samples--Table 2 Soils Sifted With 1/4 Inch Screen

Samples analyzed at NAREL in NAREL marinellis

Masses of Table 3 used to adjust activity concentrations
[e.g., For Site A, Activity * (2011/1392)]

SAMPLE NUMBER	SITE	THORIUM DECAY SERIES (Gamma Spectrometry) (pCi/g)							URANIUM DECAY SERIES (Gamma Spectrometry) (pCi/g)					OTHER (Gamma Spectrometry) (pCi/g)				TOTAL RADIUM (pCi/g)
		Ra-228	Th-228	Ra-224	Rn-220	Pb-212	Bi-212	Tl-208	Th-234	Pa-234m	Ra-226	Pb-214	Bi-214	K-40	Cs-137	U-235	Th-231	
A2.05330C	A	5.91		6.43	10.84	6.14	6.20	2.07	0.86	1.34	3.50	1.79	1.72	10.56	0.04	0.20		7.7
A2.05330C, DUP	A	5.98	7.80	6.33	10.03	6.02	6.15	2.01	3.60	2.63	3.66	1.86	1.78	10.02	0.04	0.22		7.8
A2.05326G	B-1	0.700		0.818		0.816	0.651	0.237	1.305		2.134	0.979	0.877	10.194		0.127		1.7
A2.05328J	B-2	5.29		6.07	9.24	5.37	5.21	1.79		0.84	2.22	0.97	0.93	8.92				6.3
A2.05327H	B-3	3.50		3.38		3.79	3.68	1.30	0.87		2.00	0.88	0.85	11.16				4.4
A2.05329K	C	9.04		11.07	18.87	9.62	9.49	3.30	2.70	2.38	5.38	2.54	2.42	9.15		0.32		11.6